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1 INTRODUCTION

“Electricity is of course an important factor in any economy worldwide. Changes in fuel prices, such as crude oil, natural gas and coal, lignite and hard coal, have an enormous impact on the economy, both regional and global”¹. Changing fuel prices have an influence on electricity prices, which consequently affect the economy. To estimate the changes on the electricity market, which result due to price changes, an autarkic electricity market should be investigated. On this base the Romanian electricity market suits perfectly and was therefore chosen. The Romanian power market, which consists basically of three major electricity producing forms, such as fossil fired plants, nuclear power and hydro power, has to face changes in fuel prices. Studies investigating the fuel prices were undertaken by the German Fraunhofer Institut, showing the volatility of the prices². The result of changing energy prices (higher fuel prices) will have a noticeable effect on the electricity prices as the energy prices heighten the variable costs for thermal power stations. As a result the, at the moment more expensive use of renewable sources, become profitable and replace the thermal power generating units.

The demand for all fuel kinds and electricity increased in the last ten years in “developing” countries, such as Romania and Bulgaria than in already developed countries of central Europe such as Austria or Germany³. The current Romanian electricity demand has about 55 TWh⁴ and will increase over the next periods up to a forecasted value of 73 TWh in 2050.

The future electricity demand is predicted by a macroeconomic prediction tool. The calculation is based on possible saving methods through technology improvements and increasing rates estimated by INFORSE. Kayhan et. al found out that the GDP increase has no influence of the increasing electricity

¹ Tseng et. al. (2009, p.1)

² Nitsch, Pregger & Scholz (2010, p.4-30)

³ Eurostat (2011)

⁴ IEA (2011) Electricity/Heat in Romania in 2008

consumption⁵, while Jones (1991) investigated a correlation of lifestyle changes and increasing demand⁶. All input factors are combined within a dynamic recursive simulation to estimate the total consumption of Romania. It is suggested that through the division into sectors (Housing, Industry, Transport. etc) a precise long term prediction of electricity consumption is possible. The heterogeneous approach enables thus an easier interpretation of the segments and a better understanding of the macroeconomic processes of each market. The initial point of this forecast is the current classification of all electricity consuming sectors and is based upon the observations made by the IEA (2008).

The recent discussion concerning increasing energy consumption within the European Union led to new considerations regarding the general power market and possible improvements of existing power generation units.⁷

According to bilateral agreements and national plans Romania will decrease its overall emission volume in the electricity sector by the installation of renewable generation sources. The installation, however, should be realized by means of economic aspects. Recently the Fraunhofer Institut published a study investigating the future power generation mix considering fuel price changes, CO₂ certificate changes and amendments of power plant investment costs and efficiency parameters of the various power plants. In order to calculate the specific power generation mix for the Romanian market, a linear program was established, considering the economic aspects from the Fraunhofer Institut. Under comprehension of the estimated demand, the economic aspects and added technical and utilization constraints an optimal solution was found. The interpretation is divided into three different scenarios, whereby different fuel prices were used as a base.

The main focus of the research was on the Romanian electricity consumption forecast, whereas the modelling of future demand scenarios played a minor role.

⁵ Kayhan S., Adiguzel U., Bayat T., Lebe F. (2010, p. 169 – 183.)

⁶ Jones D.W. (1991, p. 621-630)

⁷ Nitsch, Pregger & Scholz (2010, p.4 - 7)

The calculation based upon macroeconomic model-based forecasting methods provided by Krail et.al. (2007) and Wei & Hong (2009).

The calculation of the electricity mix required the usage of a professional mathematical calculation program, called IBM ILOG CPLEX Optimization Studio. The implementation of this application led to a highly satisfying result, showing the differences within the various scenarios.

The establishment of this linear programming model was the biggest challenge in terms of data collection and the further integration into the calculating program. The needed data relate in particular to all forms of existing and non existing power plants, concerning the efficiency, the use of fuel and CO₂ emission, the lifetime and the time need for installation, as well as the electricity demand and the fuel price changes within the time range of 41 years (2009 -2050). To predict the future electricity mix, the above stated data were set into relation, estimating the most cost efficient power generating park. According to the fuel price changes and the utilization for each power station, the electricity mix is investigated. The objective function of the linear programming is the minimization of costs multiplied with the discount factor over the forecasting horizon. The objective is subjected to the constraints, which are based on the decision variables of the linear program. The calculation of decision variables account for the actual results of this study, showing the future capacity and the possible usage of all power station forms as well as the expansion that indicates the extension of the generation units. Due to different fuel price scenarios the capacity and the expansion for thermal or renewable power stations varies significantly. Generally it can be said, that the capacity extension for renewable sources is higher if the fuel prices are increasing, and vice versa.

The following Master Theses is organized as follows;

- Section two provides a socioeconomic outlook
- section three describes the electricity consumption model
- section four deals with the electricity market and the merit order
- section five predicts the future electricity mix
- section six presents the Linear Programming Model
- section seven shows the calculated results.

2 AN OUTLOOK OF THE ENERGY STATUS QUO IN ROMANIA

Romania produces and consumes all different kinds of primary energy. The primary energy production was 28.782 Mtoe⁸ in 2008, while the primary energy consumption was in total 39.409 Mtoe. The imports for primary energy have a share of 35.3 percent and they are divided into shares of 14.8 percent coal and peat, 51.6 percent crude oil, 10.5 percent of oil products and 21.8 of gas products. The rest of primary energy imports are combustible renewables and waste and electricity with a common share of 1.2 percent⁹. The total amount of primary energy exports, which is not displayed in the graph below, were 5.496 Mtoe. The biggest share of export are oil products (91.4%), 8% is electricity, 0.3% is coal and peat and the rest (0.1%) are crude oil and combustible renewables and waste.¹⁰

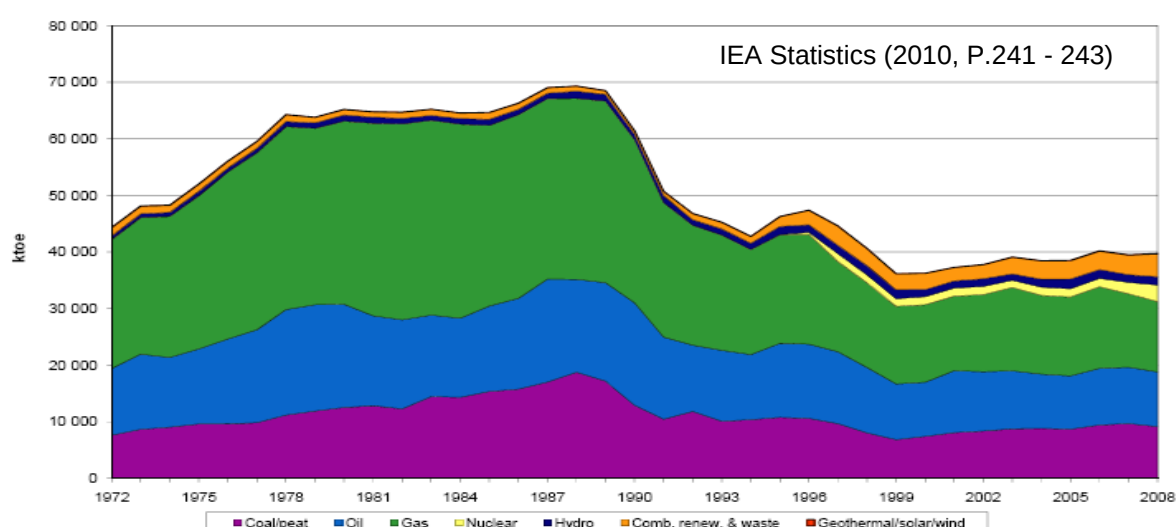


Figure 1: Primary Energy Production and Imports

The supply and consumption of primary energy in the Romanian energy market is characterized by the extensive use of coal (lignite and hard), gas, and crude oil. To meet the consumers' requirements the production of nuclear, hydro, combustible, renewable and waste energy is essential. Renewable sources for the production of

⁸ IEA Energy Balance for Romania (2008)

⁹ International Energy Agency Statistics (2010, P.241 - 243)

¹⁰ IEA Energy Balance for Romania (2008)

energy become more and more important in Romania. It increased the level of renewable sources for electricity production by 12.96Mtoe compared to the year 2007 (4.7 Mtoe in 2007, 5.4 Mtoe in 2008)¹¹. The use of renewable energy sources does not only play an important role in electricity production. The use of biomass, which is the strongest renewable primary energy source, is not only used to generate electricity, rather for heat production after combustion as well as for production of bio fuels or biogas. Hydro power is the second largest renewable source in Romania, while solar energy, geothermal and wind power play a minor role in energy production at the moment¹².

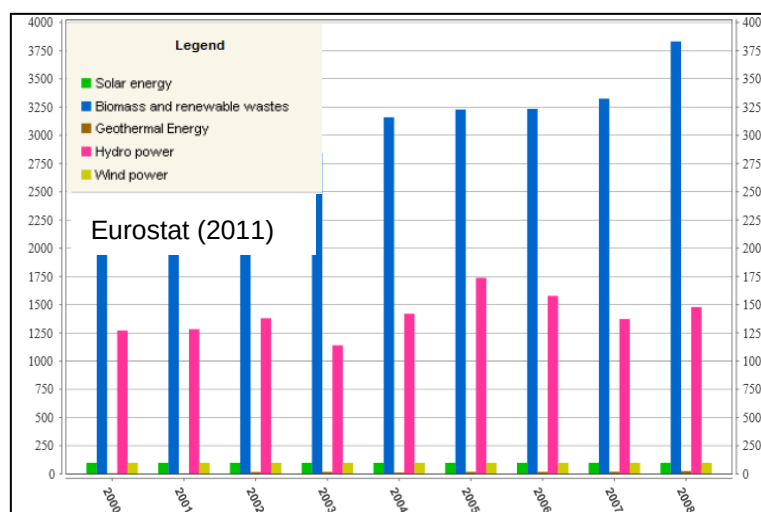


Figure 2 Renewable energy primary production (Eurostat)

The final energy demand increased constantly from 2000 to 2008 where it finally reached its maximum at a point of 24,591 Mtoe. The final energy demand is defined by Eurostat as the final energy consumption including all energy delivered to the end user, such as industry, transport, residential and other sectors. It excludes network losses, and industry's own energy use or deliveries from transformation¹³. In comparison to other European countries the rate of energy growth is still high meeting its maximum value of 4.73% in 2003 and has a

¹¹Caragea & Alexandru (2011, P. 4)

¹²Eurostat (2011) Renewable energy primary production: biomass, hydro, geothermal, wind and solar energy

¹³ Eurostat (2011) Finally energy Consumption Description

negative growth of -3.22% in 2007. The average increase in between the periods from 2000 to 2008 is at 1.06 percent.

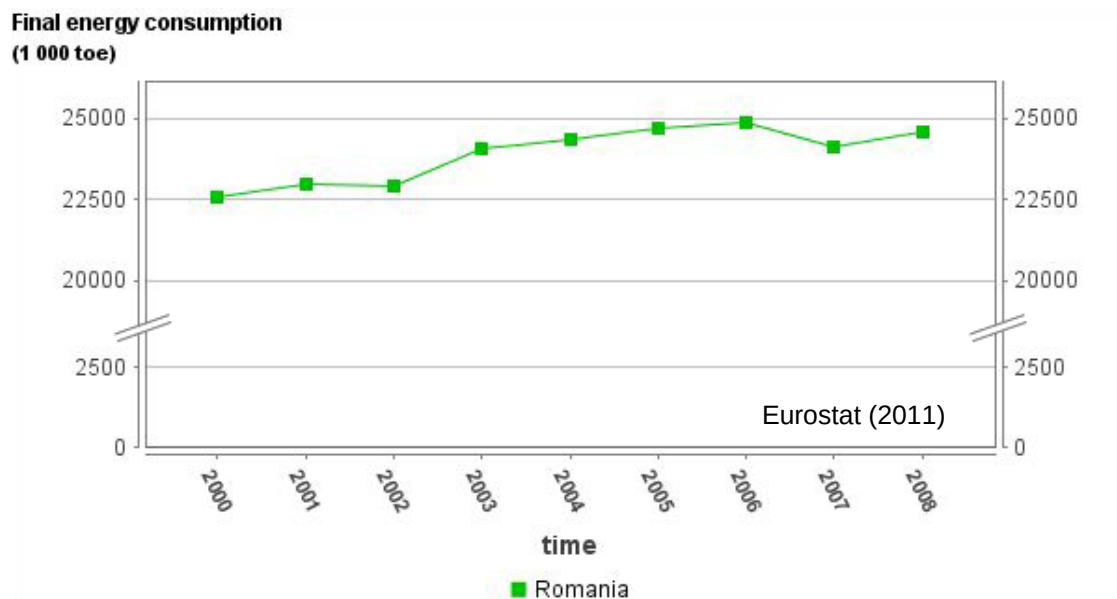


Figure 3 Final Energy Consumption

The economic growth/activity which is measured by the increase of the GDP (gross domestic product) growth rate is defined (according to Eurostat) by the value of all produced goods and services within a period minus the goods or services used to create the final product or service¹⁴. The GDP growth rate inclined in the first four years to its maximum of 8.5% in 2004 before falling to 4.2% in the following year and reaching after a slight upward trend the absolute minimum of -7.1 percent in 2009. A recovery in 2010 to -1.3 % is clearly visible in the chart below. Eurostat forecasts a further upward trend in Romania until 2012 by reaching an estimated growth rate of 3.7%¹⁵

¹⁴ Eurostat (2011a) GDP Growth Rate Description

¹⁵ Eurostat (2011b) GDP Growth Rate

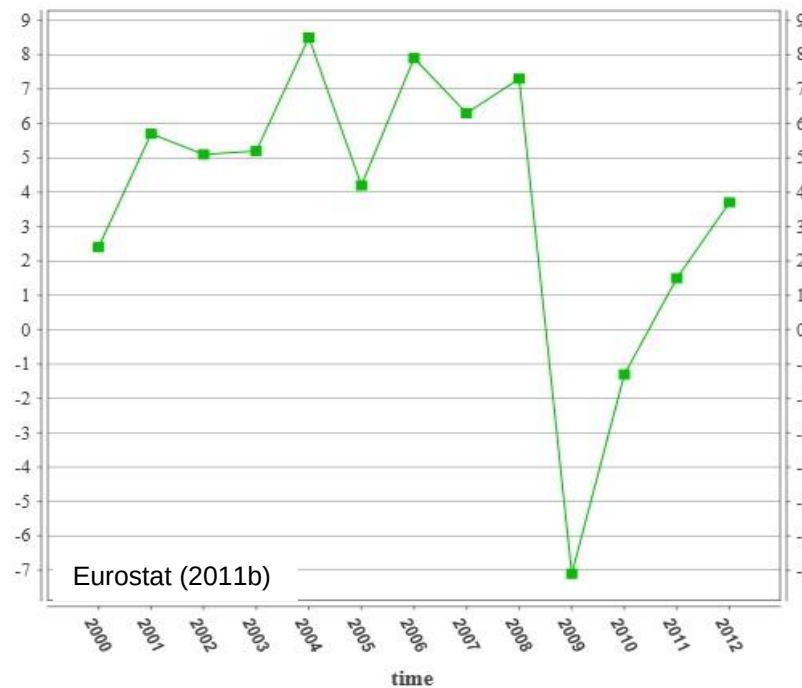


Figure 4: GDP Growth Rate

The Energy intensity is the ratio between the gross domestic product (GDP) and the gross domestic consumption of energy. It indicates the overall energy efficiency of a given economy over a certain period of time. According to Eurostat the gross inland energy consumption is the sum of the five biggest energy producing types within Romania. In this case it is the sum of coal, electricity, oil, natural gas as well as energy gained out of renewable energy sources. The ratio is defined by the gross inland consumption and the GDP taking the year 2000 as the so called reference year. The gross inland consumption is measured in kgoe (kilogram of oil equivalent), while 1,000€ are taken as a GDP equivalent.¹⁶ The energy intensity was stated in the year 2000 with 906.05 kgoe/1000€ decreasing over time to value of 612.76 kgoe/1000€ in 2008. In comparison to the EU-27 average, which is in 2008 at 167.4kgoe/1000€, the Romanian energy intensity is high.¹⁷

¹⁶ Eurostat (2011c) Energy Intensity of Economy Description

¹⁷ Eurostat (2011d) Energy Intensity of Economy

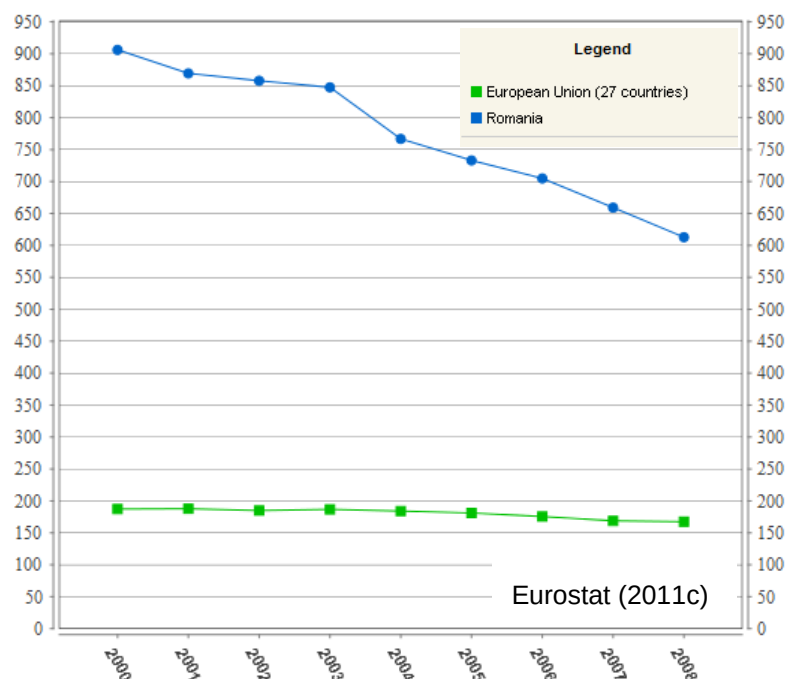


Figure 5: Energy Intensity (EU 27 & Romania)

The electricity consumption is an indicator based on the amount of used electricity per household, covering all areas using electricity in Romanian households such as water heating and electrical appliances.¹⁸ The electricity consumption of households increased in the first period (2000 to 2004) steadily from 658 ktoe to a first peak of 709 ktoe in 2003 before decreasing to a temporary minimum of 692 ktoe in 2004. After reaching its minimum an increase over the following years lead to a maximum of 894 ktoe in 2008¹⁹.

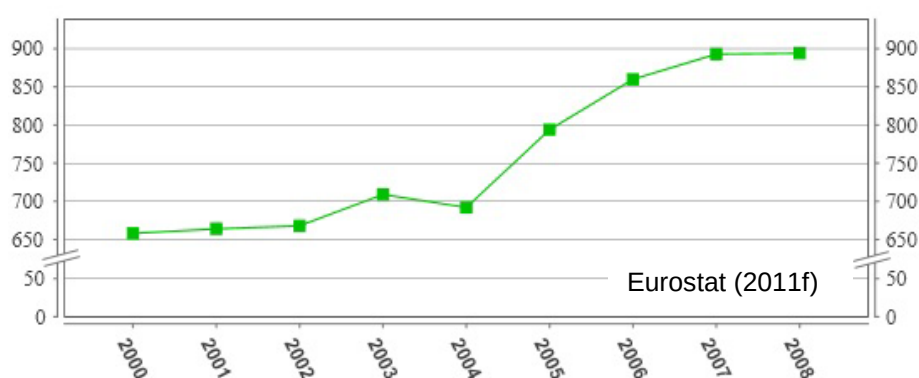
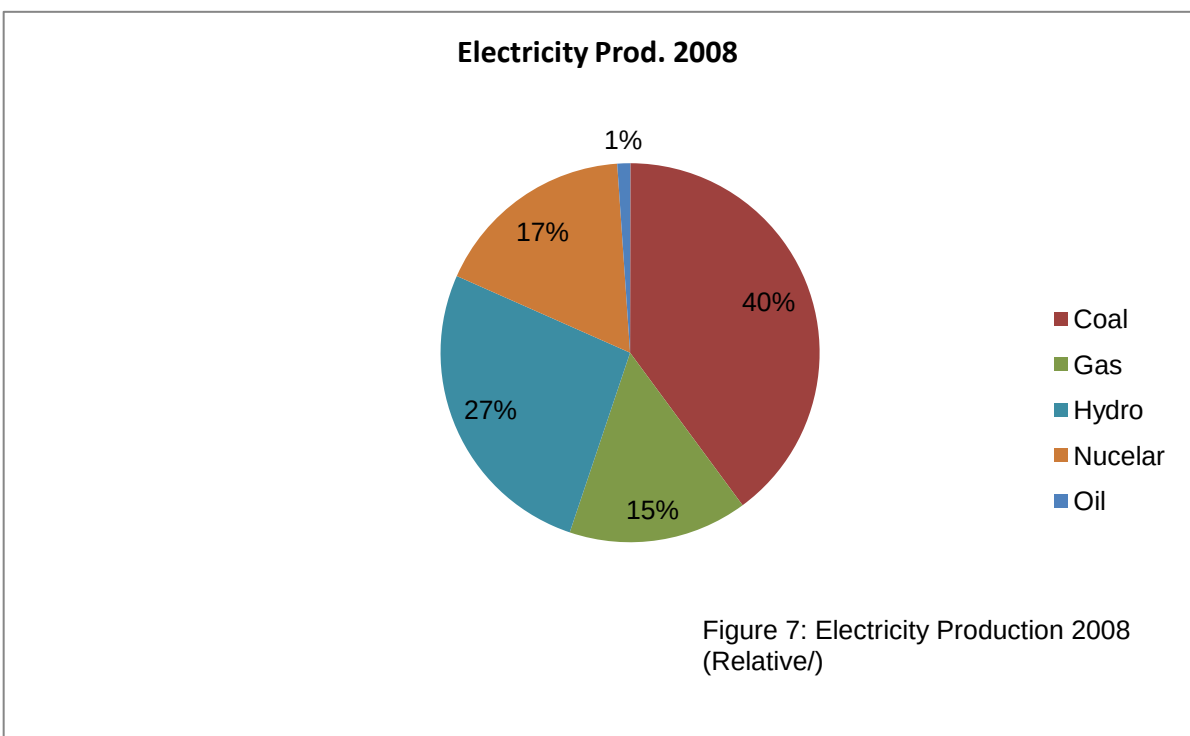


Figure 6: Electricity Consumption per Household

¹⁸ Eurostat (2011e) Electricity Consumption of Household Description

¹⁹ Eurostat (2011f) Electricity Consumption of Household

The electricity generating system of Romania is mainly based on the use of coal, both lignite and hard. 40 percent of the total electricity production is made out of coal, which corresponds to a generation of 25,882 GWh in 2008. The second biggest electricity supplying recourse is hydropower, holding a share of 27% (17,195 GWh annual productions). The third biggest party of the Romanian power market is the use of nuclear power generating systems, holding a share of 17%. The fourth biggest source are gas fired plants holding 15%, followed by oil, having one percent of the total share. Most of the electricity consumed within Romania is produced by statal power stations. The final domestic supply (60,708 GWh_a) is defined by adding the imports (921 GWh_a) and subtracting the exports (-5,169 GWh_a) to the total electricity production (64,956 GWh_a). In other words the imports of electricity have a share of 1.4%²⁰, while exports amount 7.9 percent.



IEA (2011) Electricity/Heat in Romania in 2008

²⁰ IEA (2011) Electricity/Heat in Romania in 2008

THE DEMAND MODEL

The estimation of the future electricity demand is a major concern in this study. The creation of a model was useful to understand the macroeconomic processes which increase the electricity consumption over time. The demand model forecasts the overall electricity consumption in Romania within in the time horizon 2008 – 2050. To calculate the long term electricity demand a similar model by Wei and Hong was adopted²¹. It is assumed that the demand of each sector (residential, industry, transport etc) is dependent on rates. The electricity consumption is specific for each sector and therefore the input factors for the rates vary. For simplicity it is assumed that the sectoral electricity consumption is based on two types of rates; the electricity increasing rate, which estimates the future electricity increase, and the saving rates, which determines the saving possibilities across the sectors. The significance of the demand model is undisputed. The results of the model are implemented in the linear programming problem to calculate the power generating mix within the above stated time horizon in a further step

3.1 Description of the Demand Model

The Vensim model uses as bases the latest available data connected with macroeconomic modelling methods to create a final electricity demand for the year 2050 in Romania. The model in this study covers the national electricity market by dividing each sector (transport, households, agriculture, industry, commercial and public holdings and fishing) into its own section. As a result a final electricity prediction, covering future increasing rates as well as possible electricity savings which are ascribed due to new technologies, can be calculated.

The data for the simulation are based on the IEA electricity balances 2008, INFORSE data and figures from the national institute of statistics in Romania. The selected data form the exogenous variables that underlie all kind of rates used in the model. The implementation of rates enables a forecast of subsequent periods and gives a prospect of future electricity demand scenarios. The dynamics, which correspond to a recursive simulation, have their origin in the specific consideration

²¹ Wei & Hong (2009, p.157)

of sectoral rates²². The prediction is divided into three different scenarios (realistic, optimistic, and pessimistic). The optimistic and pessimistic scenarios vary from the realistic scenario by 10% each. The idea for the model is taken from a similar case study, which is adjusted the Chinese energy market.²³ However, it is adapted to the Romanian electricity market with all its main consumption sectors.

The objective of the forecasting was to establish an interaction of modules including the consumption of each segment and the income to develop and identify scenarios for the future evolution in the electricity sector, as well as trends and tendencies in the electricity saving technologies. The adaption and integration of existing models helped to provide a detailed forecast. The scientific added value of this model contains the provision of a methodology in terms of macroeconomic analysis considering the changes in income and also the differences in rural and urban population growth.

The strategic objectives in this project are based on:

- Development of three scenarios for different prospective demands
- Building an integrated model-based approach, checking on the technology, economic and further social influences.
- Considering changes on electricity consumption habits²⁴

The output of the project shows quantitative scenarios in three different ways, combining the evolution of socio-economic²⁵ changes, technological issues and changes in the electricity consumption. The integrated modelling forecast, which is assessed over the next 42 years, interlinks the strategic objectives with the scientific considerations to create a full picture of all impacts that influence the national energy system.

²² Krail M., Schade W., et. al. (2007, p.10)

²³ Wei & Hong (2009, p.157)

²⁴ Krail M., Schade W., et. al. (2007, p.7)

²⁵ Krail M., Schade W., et. al. (2007, p.7)

3.2 Designing the Model

The past growth of electricity consumption in Romania is ascribed to the increase of population, changing from a rural to western European urban society, and to the increase of industrialization. To estimate the changes within the society an urbanization rate, which calculates the alterations from a rural to an urban society structure, is necessary. According to Donald W. Jones the urbanization has an unambiguous effect on energy consumption, which as a consequence influences the electricity consumption of a nation. In his study he claims that the industry growth and urbanization go hand in hand, showing that higher consumption of energy in urban areas increases the demand for electricity²⁶. He also investigated the transforming society – from an agricultural to an industrialized society. It is assumed that the change of the society structure corresponds to a change of a more and more energy consuming lifestyle. Due to the mechanization in the agricultural sector and the industrialization a new middle class arises as a result. In 1997 Hiroyuki published a paper investigating a correlation between urbanization and additional use of energy. He verifies the increase in electricity consumption and the increase in electricity consumption per capita, respectively, according to the higher degree of industry in urban areas.²⁷ Following the study of Sathaye and Meyers - electricity consumption grows by additional income. This is verifiable through the increase of modern technology used in households and the higher life standards generated through the rising household income and the growth of the gross national product.²⁸

The forecast for the final electricity consumption is divided into six different categories, following the different sectors listed in the IEA's energy balance for Romania; Industry, Transport, Residential, Commercial and Public Services, Agriculture / Forestry and Fishing.

To link these sectors with the above mentioned rates a pattern, visible in figure 8, was established, to calculate the final power demand. The relationship in-between

²⁶ Jones D.W. (1991, p. 621-630)

²⁷ Hiroyuki I. (1997 p.45)

²⁸ Sathaye J., Meyers S. (1985 p. 75-76)

the structure was adopted from the case study “Calculation of energy demand, energy Structure and CO2 Emissions in China (2010 – 2030)²⁹”, written by Zhou Wei and Mi Hong. In the following figure the structure of the forecast and the dynamic system of the model is shown.

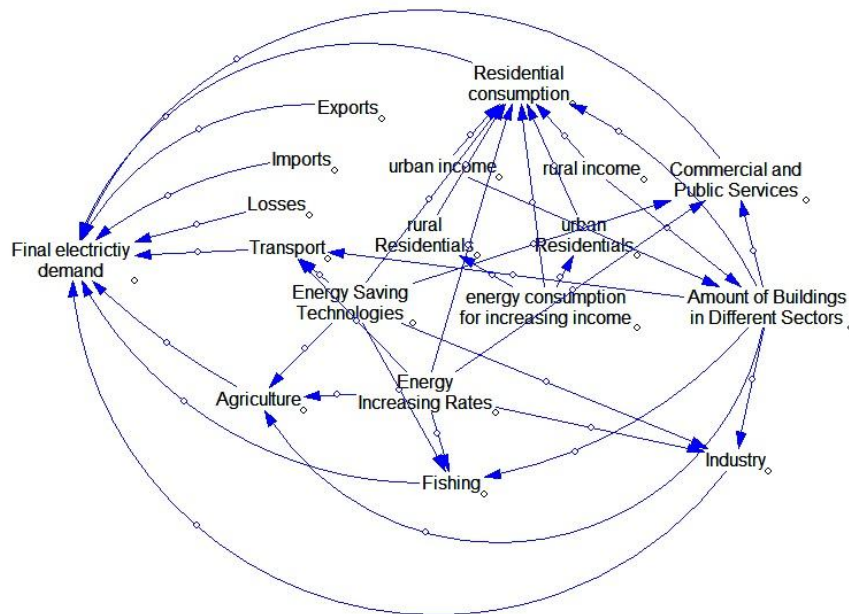


Figure 8 the Model used to predict future electricity demand, developed in Vensim

The Demand Model is structured in modules. A module describes a section which is changed by rates. The rates mentioned above are defined by input factors, which affect the sectors individually. The base of electricity consumption change due to rates is the amount of buildings, differentiating by module. In order to measure the electricity consumption for the residential sector, it is necessary to understand the population development. To calculate the amount of Buildings for the residential sector, it is assumed, that the average amount of people living in a building is constant,

$$\left(\frac{\text{Total Population}}{\text{Amount of people living in urban buildings}} = \text{Amount of Urban Buildings} \right)^{30},$$

while in the other modules it is assumed that the amount of buildings are constant within the planning horizon. The following graph explains the structure of the demand model.

²⁹ Wei & Hong (2009, p.157)

³⁰ Same equation for rural households

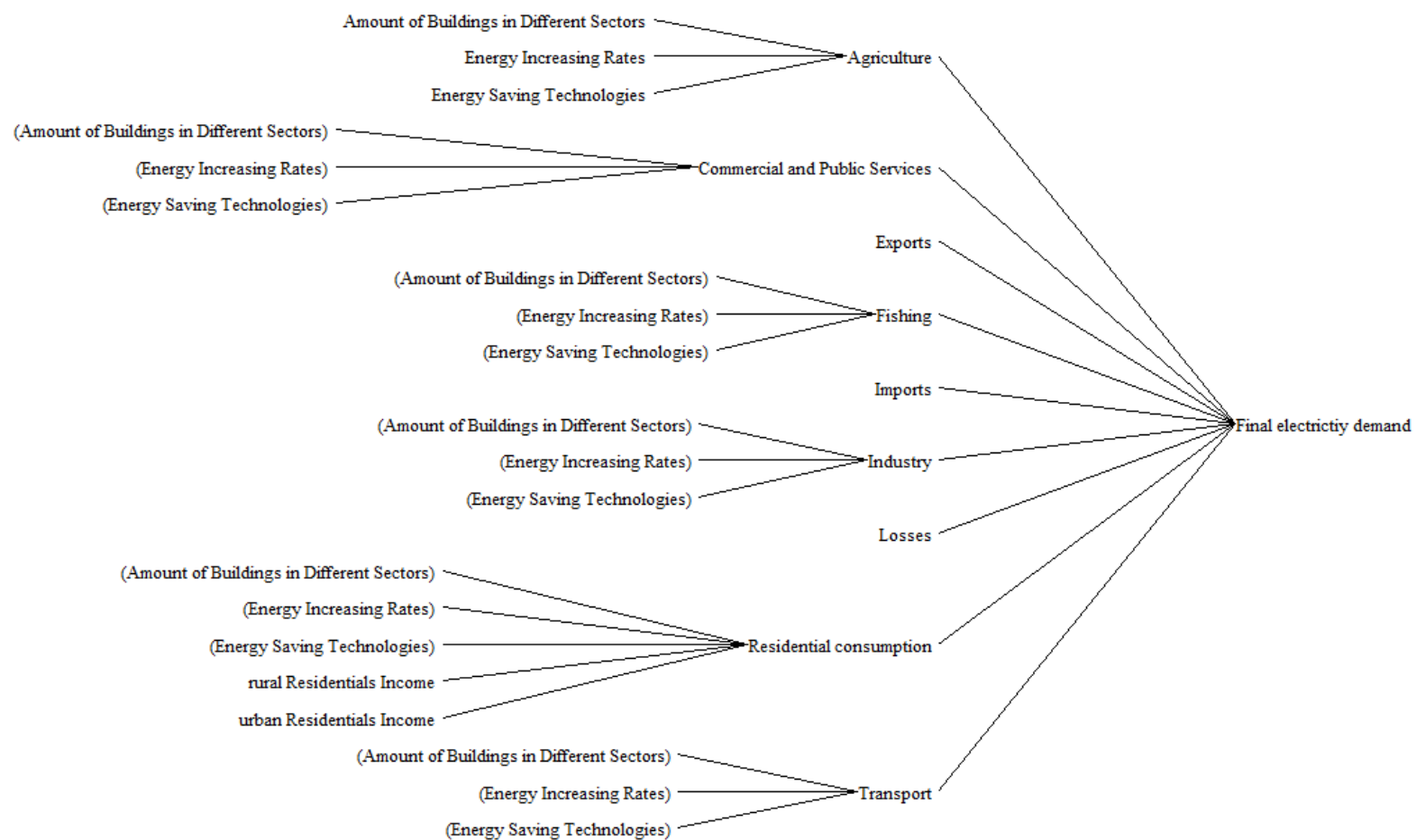


Figure 9: Structure of the Demand Model³¹

³¹ Exports, Imports, Losses are constant over the planning horizon, and not changed by any rates

3.2.1 Influencing Rates

Before each sector is analysed, all input factors and equations are discussed. The first and most complex module (Residential Consumption) has three different rates (Energy increasing rate, income and the electricity saving), influencing the electricity use: In the other modules, “Industry”, “Transport”, “Fishing”, “Agriculture and Forestry” and “Commercial and Public Services”, only saving methods and the general electricity increasing rate have an impact on the consumption.

3.2.1.1 The Gross Domestic Product (GDP)

A study from the Institute of Economic Forecasting of Romania investigates the interaction between the Gross Domestic Product and the electricity growth in Romania. In contrast to Donald W. Jones description and proof of GDP influences in electricity consumption in developing countries³² the Institute of Economic Forecasting explores the causality relationship between real GDP and electricity consumption only for the Romanian market.

The methodology used in this forecast is divided into two causality tests among the variables GDP and the electricity consumption (given in GWh). The causality tests, Dolado-Lütkepohl (1996) and Toda and Yamamoto (1995) will be compared in the end with the traditional Granger causality³³. The outcome of the first two causality tests demonstrates causality between electricity growth and GDP but no causality was found between GDP and electricity growth. To verify the results, the Granger causality test was applied. The results match with the first two tests; no causality between GDP and electricity growth is given!³⁴

3.2.1.2 Energy Saving

Energy saving methods will play a superior role in future energy consumption. The challenges the Romanian energy market has to face are on national and on global level. Challenges are

- security of energy supply,

³² Jones D.W. (1991, p. 621-630)

³³ Kayhan S., Adiguzel U., Bayat T., Lebe F. (2010, p 175)

³⁴ Kayhan S., Adiguzel U., Bayat T., Lebe F. (2010. P 180-181)

- decrease of a negative impact of energy producing on the environment
- increase in economic competitiveness

For the Romanian energy market it is important to reach a similar economic performance level of more developed nations in the European Union. According to the national action plan for energy efficiency an increase of energy efficiency is essential to fulfil the objectives mentioned above. A legal and institutional framework (in conformity with the European Union) was created to promote energy efficiency all over Romania.³⁵

National Targets for energy saving

The energy saving is different to the electricity saving. However, since one cannot neglect the economic potential of energy saving it is shown in the following table. In the following table the sectoral potential of energy saving in percent and ktoe is shown.

Sector	Average potential energy saving (in percentage of consumption)	Maximum value of potential energy saving (ktoe/year)
Industry	13%	1590
Residential	41.5%	3600
Transport/Communications	31.5%	1390
Tertiary (service) sector	14%	243
Total	100%	6823 ³⁶

Table 1: Consumption of all Sectors³⁷

To estimate the electricity saving another study by the Wuppertal Institute for Climate, Environment and Energy is used. As there are no usable data for the Romanian electricity market, concerning potential electricity savings, given, data

³⁵ First National Action Plan for Energy Efficiency (2006, P. 3)

³⁶ First National Action Plan for Energy Efficiency (2006, P. 5)

³⁷ First National Action Plan for Energy Efficiency (2006, P. 5)

concerning future electricity savings are overtaken and adopted from the German market.

The study investigates energy end use utilization and significant opportunities for the electricity market. The objectives of this study are:

- To give an overview of technical possibilities concerning the energy sector
- The quantification of the energy end use efficiency in Germany and the transferability of the results to other European nations
- Investment needs to realize technological and economic issues for electricity saving measures.³⁸

In the following table the electricity consumption in percent of total consumption by sector is shown. In addition the electricity saving potentials for the investigated time horizon is shown. Since Romania wants to decrease its electricity consumption, the input of possible savings are necessary. It is assumed, that the Romanian electricity market carries out saving methods which reaches in 42 years the German electricity savings goal of 2015. Therefore the percentage of electricity saving potentials, shown in the table below, is overtaken and the amount of electricity savings in GWh is adapted according to the percentages to the Romanian Market. Thus Germany has a different status quo concerning electricity savings in current consumption, the long runtimes for potentials savings, in the Romanian consumption market, are justifiable. Interesting for this master thesis however are the electricity saving potentials (in percent) shown at the end of each sector. Unfortunately there are no data for fishing found in appropriate literature. It is believed that it has the same electricity saving potential as the agricultural sector.

Sector	Percent of total consumption	Consumption and electricity saving potential (in GWh)
Industry	54.98%	22987
Potential Energy Saving in Industry	19.50%	4482.5

³⁸ First National Action Plan for Energy Efficiency (2007-2010, P. 5)

Transport	3.44%	1439
Potential Energy Saving in Industry	18.00%	259.1
Private Buildings	24.87%	10400
Potential Electricity Saving in private Buildings	28.60%	386.7
Commercial and Public Services	15.38%	6432
Potential electricity saving in Commercial and Public Services	21.50%	1382.9
Agriculture/Forestry	1.32%	554
Potential Energy Saving in Agriculture	30.00%	166.2
Fishing	0.00%	1
Potential Energy Saving in Fishing	30.00%	0.3
Total Savings	100.00%	41813

Table 2: Electricity Saving Possibilities by Sector³⁹⁴⁰

Within the European Union there are obviously differences in electricity consumption and saving potentials respectively. In the residential sector lighting, old electricity wasting refrigerators and washing machines and different habits of nutrition in Eastern Europe result in higher usage of electricity and bad energy efficiency correspondingly. Other areas in household, such as communication technologies and entertainment electronics, comparability between all European nations is given. Improvement in the Eastern European countries is made regarding insulation on existing buildings, even though there are additional requirements necessary⁴¹. Nevertheless a change in heating supply is foreseeable. Until now, most of the Romanian heat supply is covered by black coal

³⁹ Barthel Bunse Irrek (2006, P. 2)

⁴⁰ GWh data are taken from IEA Country Balances

⁴¹ Barthel Bunse Irrek (2006, P. 12)

or lignite⁴², which surely will change in a certain period of time.⁴³To enforce the Romanian energy saving plans, actions have to be carried out. The Romanian government divides the action plan in several categories, which ensure expansion of electricity saving methods.⁴⁴

3.2.1.3 Electricity Increase based on Lifestyle Changes

As already mentioned above, a change in lifestyle causes also a change in energy consumption. The difference in electricity consumption is measured by the change in lifestyle which is reflected in income⁴⁵. To create an income rate it is assumed that the average Romanian income will reach the Austrian income of 2009 in 2050. In the Austrian institute of statistics no differentiation between urban and rural income is made. Further it is to mention that no differentiation between the rural/urban electricity consumption is listed in the National Institute of Statistics in Romania; consequently the author assumes that the rural consumption deviates according to the income of urban areas.

⁴² IEA Energy Balance for Romania (2008)

⁴³ Barthel Bunse Irrek (2006, P 18)

⁴⁴ First National Action Plan for Energy Efficiency (2007-2010, P. 6)

⁴⁵ Jones D.W. (1991, p. 621-630)

	Income/Household	Consumption/Household
Romania	Urban:7,487€	948kWh ⁴⁷
	Rural: 5,490€ ⁴⁶	695.14kWh ⁴⁸
Austria	Total average: 29,849€ ⁴⁹	1412kWh ⁵⁰

Table 3: Income and Consumption by Households

If Romania reaches the income of the Austrian 2009 level in 2050, it will increase its urban income by 532.4 Euro, while the rural income rises by 580 Euro annually. Estimating the increase in relative figures, the urban income will grow about 3.35% annually and the rural grows by 4.11% per year⁵¹. In order to calculate the increase of electricity consumption due to income increases in urban areas the overall consumption increase must be considered. The consumption increase in urban areas is 11.05 kWh/year, while the increase in rural areas is 17.07 kWh/year. If now set the consumption and the income in relation, the kWh increase for one additional earned euro can be estimated. In urban areas one additional earned euro increases the consumption by 0.022 kWh in rural areas by 0.029kWh respectively. This means that consumption increases by 0.953% in urban and by 1.702% in rural areas annually.

3.2.1.4 Electricity Increasing Rates

Apart from the increase in electricity consumption due to changes of life style habits, each module has an electricity increase rate which is used in the forecasting model. Each sector has its own increasing rate that is implemented into the model by segment. The following table shows the differences in the sectors.

⁴⁶ National Institute of Statistics Romania (2009 p 10)

⁴⁷ Eurostat (2011e) Electricity Consumption of households

⁴⁸ Rural Consumption = $948/7.487 \times 5.490$

⁴⁹ Statistic Austria (2009) Household Income

⁵⁰ Eurostat (2011e) Electricity Consumption of households

⁵¹ No statistical income data for 2008 were available in Romania.

Sector	Average Annual Increase in Percent	Increase Indicated by Inforse (year 2000)
Industry	1.41% p.a.	1.8 times
Transport	2.21% p.a.	2,5 times
Residential	1.70% p .a.	2,03 times
Commercial and Public Services	2% p.a.	2,3 times
Agriculture / Forestry	No change	No data available
Fishing	No change	No data available

Table 4: Increasing Rates of all Sectors⁵²

As there are no data for the agricultural and the fishing sector available, no change in the electricity consumption is assumed. According to Inforse (International Network for Sustainable Energy) the growth of the electricity demand corresponds to larger dimensions of living, higher requirements of transported and the greater demand for industry products and goods and service⁵³. According to Inforse the increase for energy consumption is almost slow in the first decade (2000 – 2010)⁵⁴, therefore it is supposed that the data from 2000 are still valid.

For the other scenarios (Optimistic/Pessimistic) the same data are used as basis; Pessimistic is 10% higher than the realistic scenario, assuming a higher increase of electricity consumption - Optimistic is 10% lower than the realistic scenario, whereby a lower increasing rate was implemented into the model. Only for the Agriculture/Forestry and Fishing sectors the data stay constant as in year 2008. The naming of the alternative scenarios was made by the assumption that the higher increase of electricity consumption conflicts with the electricity saving targets of Romania and vice versa.

⁵² INFORSE-Europe (2007, p.3-6)

⁵³ INFORSE-Europe (2007, p.3-6)

⁵⁴ Pamantului & INFORSE-Europe (2007, p. 2-5)

3.2.2 Description of the Modules

In the following chapters each sector within a module is described in detail - from the data origin and the connection to the other modules to the outcome. As a basis all sectors use the amount of electricity consumed in one building. Starting with the consumption of buildings a dynamic forecast can be provided.

3.2.2.1 Population Changes

To calculate the increase of urbanization in terms of a rate it is necessary to know the growth rate of the population, both in the urban sector and in the rural sector respectively. The urbanization within more agricultural countries proceeds rapidly. According to Colombo et al. more than 48 percent of the world's population are living in cities or in urban areas⁵⁵. In Romania the urban population accounts for 57% of total population and the urbanization rate is 0.6%⁵⁶ per year. The population decreases by 0.252% annually. The birth rate is stated with 9.55 births per 1000 inhabitants and a death rate with 11.81 deaths per 1000 people in 2011⁵⁷. As there are no utilizable data for urban or rural population growth given in the Romanian national institute of statistics, the growth of population is assumed in both areas equally. As mentioned above, the percentage of people living in urban areas is known, and amounts 12,485,594.07 inhabitants while 9,418,957 inhabitants live in rural areas. The total population of Romania is now reckoned to be 21,904,551 inhabitants, decreasing over the next 50 years constantly to a minimum of 19,968,900 inhabitants in the year 2050. Figure 10 Total Population changes in 2050 shows the decrease of population within the given period.

⁵⁵ Colombo, Demeny, Perutz (1996, P262)

⁵⁶ CIA World Factbook (2009) Population

⁵⁷ CIA World Factbook (2009) Population

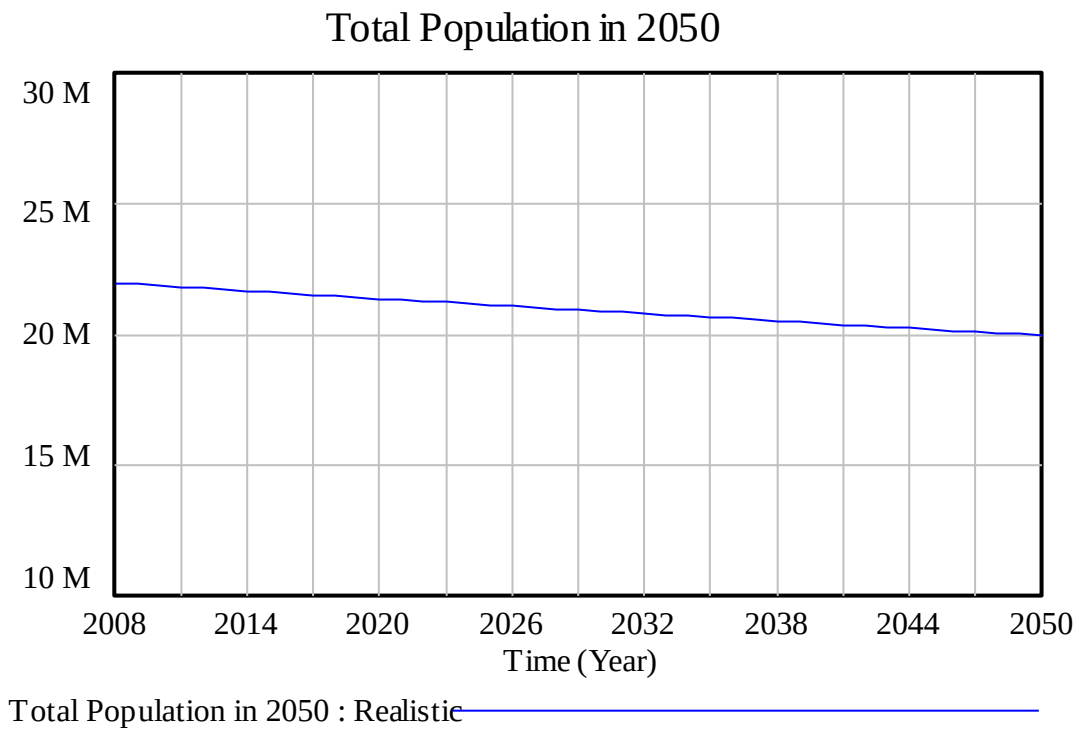


Figure 10 Total Population changes in 2050

As stated above, a tendency from an agricultural society to an industrial one is given. Therefore an urbanization rate is calculated to estimate the new structure of the society in future years.

3.2.2.2 Urbanization Rate

To investigate the change of a society structure, a rate to measure urbanization is necessary. Apart from the given urbanization rate from the CIA World Factbook, an urbanization rate, developed by Keyfitz Nathan, a well known scientist in fields of demography, is implemented into the study. The same rate, already used by the Chinese researchers Wei & Hong, revealed a highly satisfying result. Keyfitz estimates the migration of population by setting the urban population at time $P_u(t)$ in relation to the rural population at the same time $P_r(t)$. r and u describe the natural rates of increase of the rural or the urban inhabitants. Following the theory of Keyfitz the urbanization rate can be written as⁵⁸:

⁵⁸ Wei & Hong (2009, p.159)

$$\Phi(t) = \frac{P_U(t)}{P_r(t) + P_U(t)}$$

Implementing this formula into the simulation software following result of the migration movement is provided:

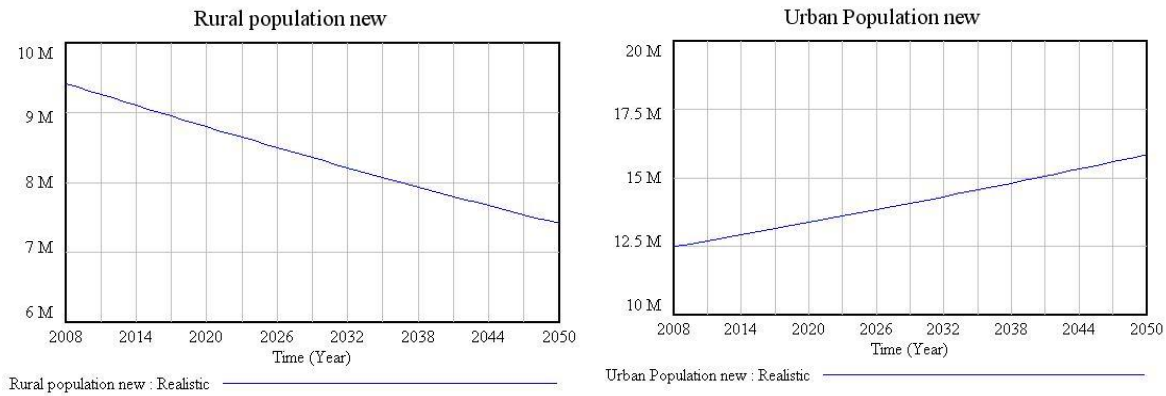


Figure 11 Changes of the Rural Population and Urban Population

The rural population will decrease by 0.57%, while the urban population increases by the same amount in 2008. Since the population structure is changing due to urbanization the urbanization rate is changing as well. The urbanization rate therefore amounts in 2050 already to 0.68%. This result is received by the insertion of the urban/rural population(t) in the above stated formula. Looking at the estimation of the CIA World Factbook (0.6% p.a.), the formula provided by Keyfitz has almost the same outcome.

3.2.2.3 Residential Consumption

The residential electricity consumption is calculated by subtraction. The electricity saving measures is subtracted from the electricity use per building. First of all it is important to know the amount of people living in the buildings, in the urban, as well as in the rural areas of Romania. The Romanian National Institute of Statistics offers data concerning the number of people living in the buildings dividing the country into eight different districts, which include all counties. To estimate the amount of people living in an average urban private buildings the amount of buildings of the seven biggest cities (Iasi, Galati, Timisoara, Cluj – Napoca,

Constanta, Brasov and Bucharest) are taken and divided by urban population. In order to calculate the rural amount of people in buildings the non urban amount of buildings are used, resulting in an average of 2.97 people per rural buildings and 2.86 per urban buildings⁵⁹.

The amount of buildings is calculated as following: The rural/urban population is divided by “number of people living in rural/urban buildings”. This number is important to approximate the electricity consumption of all rural/urban buildings in Romania. In this dynamic model the total residential consumption of 2008 was taken to calculate the rural/urban resident consumption by setting the total amount of buildings in relation with the rural/urban amount of buildings. Concluding the formula can be written as following:

Total Resident Consumption ... C_r

Amount of Rural Buildings ... RB_t

Amount of Urban Buildings ... UB_t

Total Amount of Buildings ... TB_t

$$\text{Total Rural Resident Consumption} = C_r * \frac{RB_t}{TB_t}$$

$$\text{Total Urban Resident Consumption} = C_r * \frac{UB_t}{TB_t}$$

To calculate the electricity use of a module, increasing rates and saving rates have to be implemented. In order to calculate the electricity use of a module the electricity use per building has to be calculated at first. Since the amount of buildings distinguishes in the urban or rural sector and due to the different increasing rates (income rate), the overall electricity consumption differs, which makes a social differentiation necessary. The *electricity use per rural building $ElecRB_t$* and *electricity use per urban building $ElecUB_t$* is simply calculated by the division of *Total Rural Resident Consumption* or *Total Urban Resident Consumption* and the *Amount of Urban Buildings (RB_t)* or the *Amount of*

⁵⁹ National Institute of Statistics Romania (2009. p 1)

Rural Buildings (UB_t). The further calculation of the electricity consumption expects on the one hand the implementation of electricity increasing rates (Energy Increasing Rates and Income) and on the other hand the electricity saving possibilities during the periods.

The above mentioned increasing rate is connected to the electricity consumption per building. As shown in Table 4: Increasing Rates of all Sectors, the growth of electricity consumption is defined. A further influencing factor of future electricity consumption is the income changes per buildings, which is presented in table Table 3: Income and Consumption by Households.

The urban electricity use rate UE_t , corresponds to the above mentioned increasing rates as well as to electricity use of urban buildings. The increase of urban consumption is therefore defined as following.

$$UE_t = (UICR_t + UIR_t) * ElecUB_t * UB_t$$

Where $UICR_t$ is the Urban Income Rate and UIR_t is the Increasing Rate, $ElecUB_t$ is the *Electricity Use Per Urban Building* and UB_t is the *Amount of Urban Buildings*.

The same equation is used for the Urban Electricity Use Rate – just the input factors are different: instead of the urban figures the rural figures are implemented.

$$RE_t = (RICR_t + RIR_t) * ElecRB_t * RB_t$$

Rural Electricity Use Rate ... RE_t

Electricity Use Per Rural Building ... $ElecRB_t$

Rural Income Rate ... $RICR_t$

Rural Increasing Rate ... RIR_t

Amount of Rural Buildings ... RB_t

The urban electricity saving is calculated by the urban electricity saving rate $UESR_t$, using the electricity saving data from section 3.2.1.2 (electricity saving).

Therefore the equation can be written as

$$UESR_t = UES_t * ElecUB_t * UB_t$$

, where $ElecUB_t$ is the *electricity use per urban building* and UB_t is *Amount of Urban Buildings*

The same equation is applied for the rural situation to calculate the rural saving possibilities $RESR_t$ over time, where

Rural Electricity Saving ... RES_t

Electricity Use per Rural Building ... $ElecRB_t$

Amount of Rural Buildings ... RB_t

Since the final electricity use of rural or urban Buildings is desired result, the urban or rural electricity saving UES_t or RES_t has to be subtracted from the rural or urban electricity use rate UE_t or RE_t . The initial value of this subtraction is total rural or urban resident consumption, explained above.

For a better understanding the linkage between all equations mentioned above is shown in following figure:

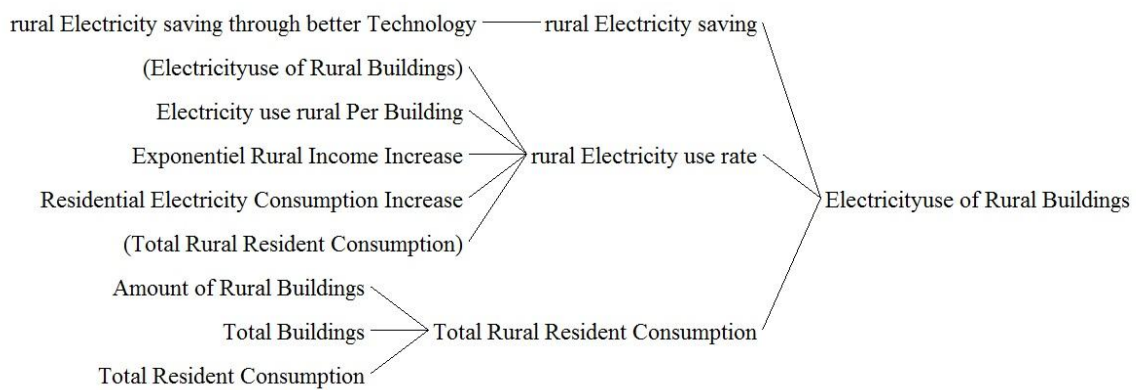


Figure 12: Linkage between the Input Factors

Below the three scenarios in the electricity use of rural buildings are visible, whereby the starting point is equal at 4,391.56 GWh in 2008. The realistic scenario increases in 2050 up to 5,715.72 GWh, while the optimistic has 5,545.69 GWh and the pessimistic 5,890.82 GWh in the year 2050.

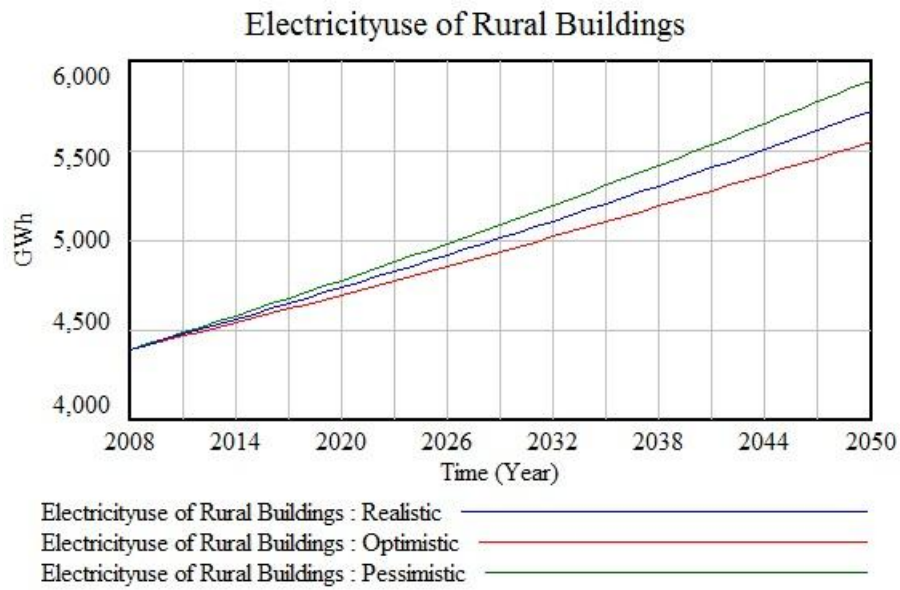


Figure 13: Electricity use of Rural Buildings

On the other hand the electricity use of the urban buildings start at 6,005.64 GWh in 2008 increasing in the realistic scenario up to 7,816.16 GWh in 2050. The pessimistic (optimistic) changes from the same starting point to 8,055.61GWh (7,583.66GWh) in 2050:

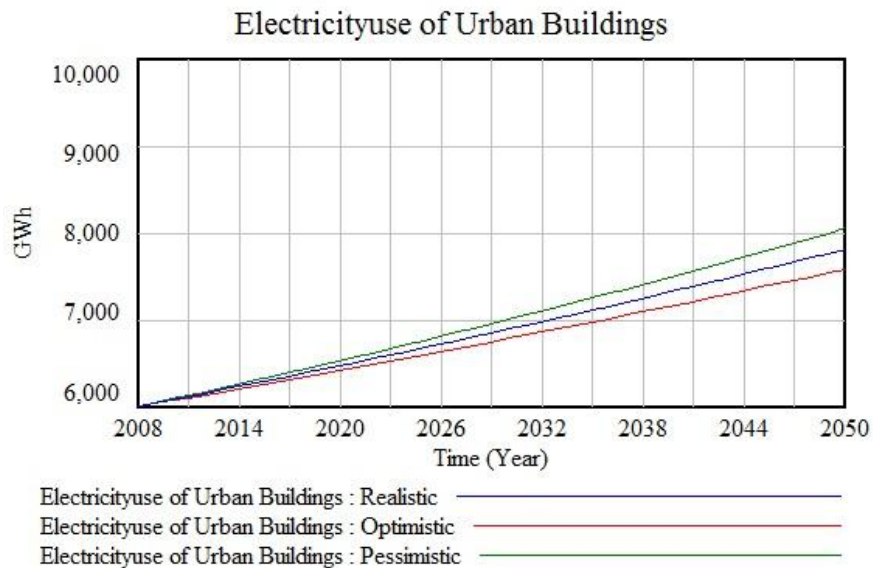


Figure 14: Electricity Use of Urban Buildings

Since the rural electricity use of all buildings with the urban electricity use of all buildings is aggregated, the total residential electricity use within the planning horizon can be provided. Starting at 10,397.2 GWh in 2008 increasing of time in the realistic scenario to 13,531.9 GWh, in the pessimistic (optimistic) to 13,946.4 (13,129.4) in 2050.

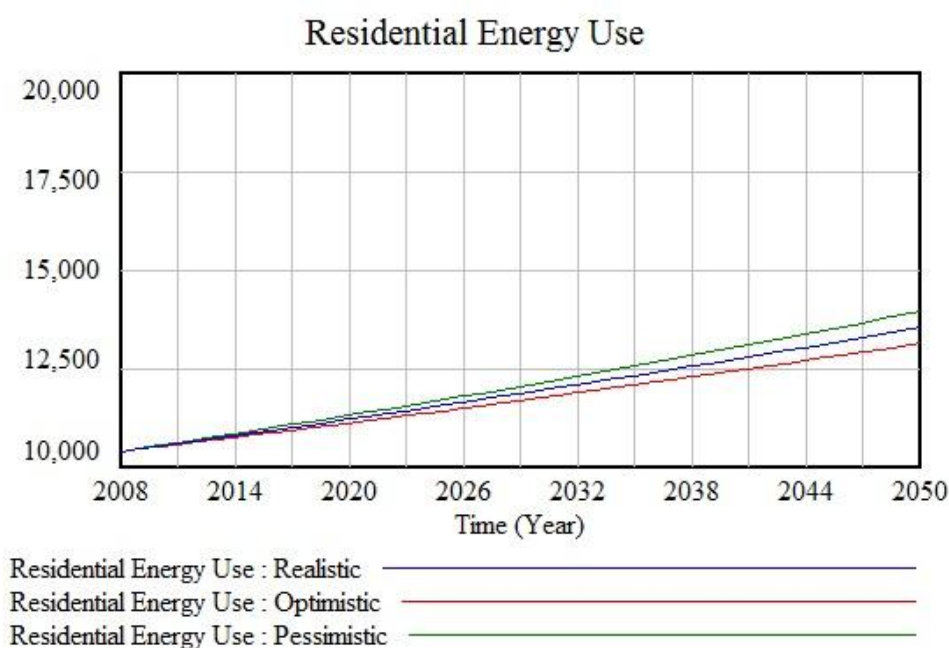


Figure 15: Residential Electricity Use

3.2.2.4 Agricultural Consumption

In the agricultural electricity consumption the farming and forestry sectors are aggregated. Similar to the residential consumption the amount of agricultural buildings is used as a basis. Assuming that all buildings use the same amount of electricity the consumption of 2008 was taken and divided by all agricultural buildings. The amount of agricultural buildings was according to Eurostat 3,931,350⁶⁰ and the amount of forestry firms was stated with about 7,000⁶¹ buildings. The increase of the agricultural electricity use is assumed to be zero, the possible saving objective of 30% is spread over the next 42 years until the end of the forecasting period (taking 2008 as a base year). The causes tree, shown

⁶⁰ Eurostat (2011g) Number of agricultural buildings

⁶¹ Encyclopedia of Nations (2011) Forestry

below, explains the linkage of the electricity consumption within the agricultural sector.

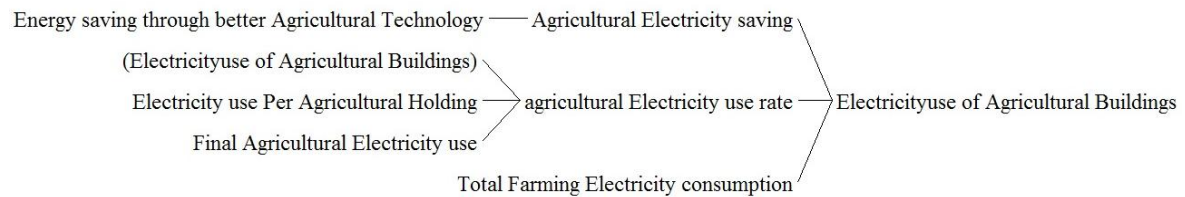


Figure 16: Linkage between Agricultural Input Factors

The agricultural electricity use rate is zero, while the agricultural electricity saving rate is calculated as equally as the rural or urban electricity saving rate.

$$AESR_t = AES_t * ElecAB_t * AB_t$$

Agricultural Electricity Saving ... RES_t

Electricity Use per Agricultural Building ... ElecRB_t

Amount of Agricultural Buildings ... RB_t

By subtracting the agricultural savings (t) from the initial value, the total farming electricity consumption, the electricity use of agricultural buildings can be computed. As already mentioned above, it is assumed that there is no additional increase of electricity in the agricultural sector, therefore only the realistic scenario exists. In the graph below it is clearly visible that the Electricity use of Agricultural Buildings is decreasing over time, starting at 558.24⁶² GWh in 2008 descending to 390,751 GWh in 2050.

⁶² IEA Electricity/Heat in Romania (2008)

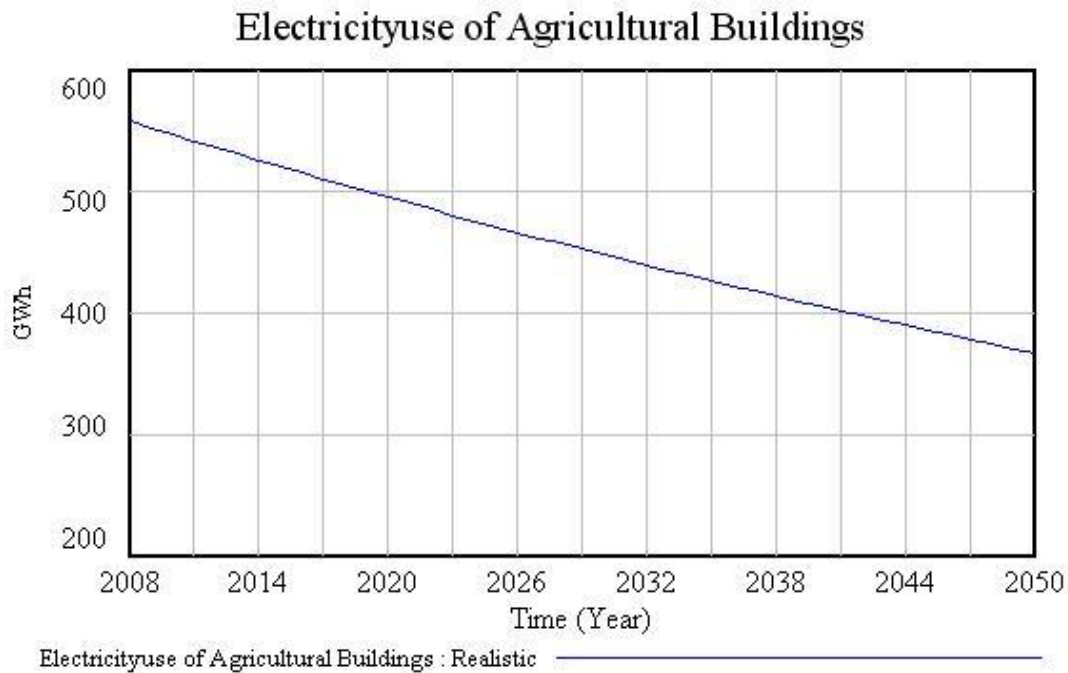


Figure 17: Electricits Use of Agricultural Buildings

3.2.2.5 Industrial Consumption/Transport Consumption/Commercial and Public Services Consumption/Fishing Consumption

For the industrial, transport, commercial and public services and fishing sector, the model structure of electricity consumption is the same, only the input numbers differentiate. For that reason only the model is explained, nevertheless the graphs will be described precisely for all sectors.

The base used in the sectors Industry, Transport Commercial and Public Services and Fishing are the buildings and the total consumption. To get the electricity demand per building the total electricity consumption is divided by the amount of buildings of each sector.

Sector	Amount of of Buildings	Electricity Consumption in 2008 (In GWh)
Industry	10773	22992.5
Transport	36487	1442.12

Commercial and Public Service	2270463	6431.39
Fishing	37764	165

Table 5: Amount of Houldings and Electricity Consumption of Sectors

The Electricity Use Rate, which results out of the multiplication of the electricity increase rate and the electricity use per Building and the total amount of all buildings, heightens the electricity use of each sector. On the other hand each region has the possibility to save electricity due to technology improvements (chapter 3.2.1.2 Energy Saving). To forecast the electricity use of all buildings (by sector) the electricity saving possibilities are subtracted from the electricity increase over time, starting from the electricity consumption in 2008.

Industrial Consumption

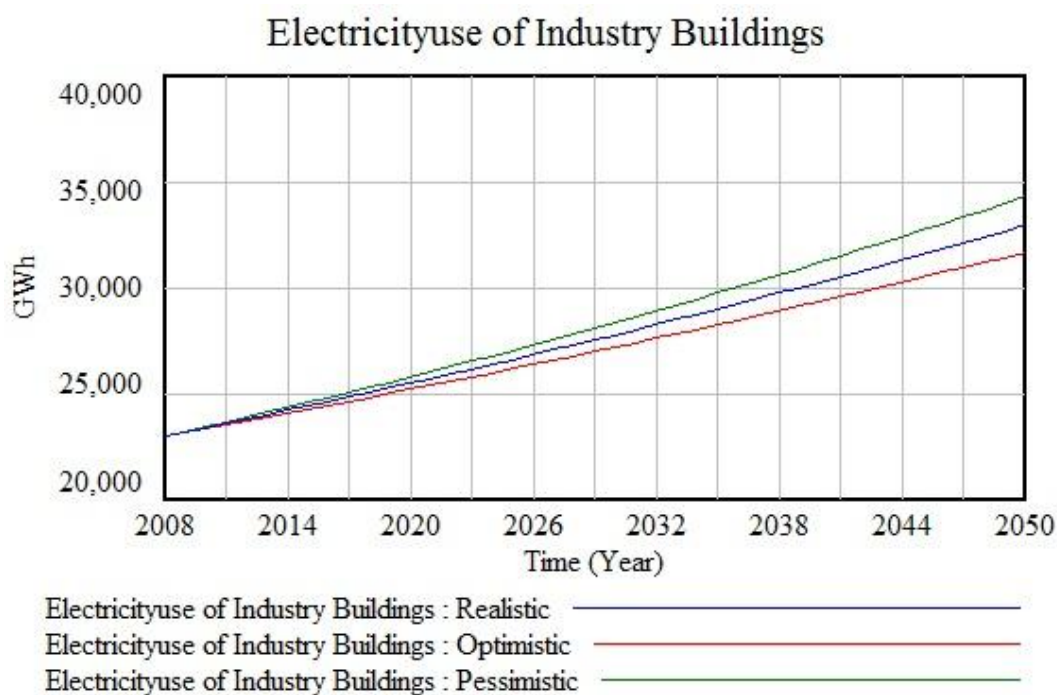


Figure 18: Electricity use of Industry Buildings

The electricity Consumption of Industry Buildings rises in the planning horizon from 22,992.5⁶⁶ GWh in the realistic scenario up to 32,958 GWh, in the optimistic scenario up to 31,665 GWh and in the pessimistic scenario up to 32,301.6 GWh.

⁶³ Eurostat (2011h) Number of enterprises by sector

⁶⁴ Kühnhold (1998 p. 199)

⁶⁵ IEA Electricity/Heat in Romania (2008)

Commercial and Public Service Consumption

In the graph below the electricity consumption of the commercial and public service sector is visible. All three scenarios start at 5,431.39⁶⁷ GWh in 2009 increasing to 11,458,8 GWh in the realistic, 10,754.7 GWh in the optimistic and 12,207.8 GWh in the pessimistic scenario.

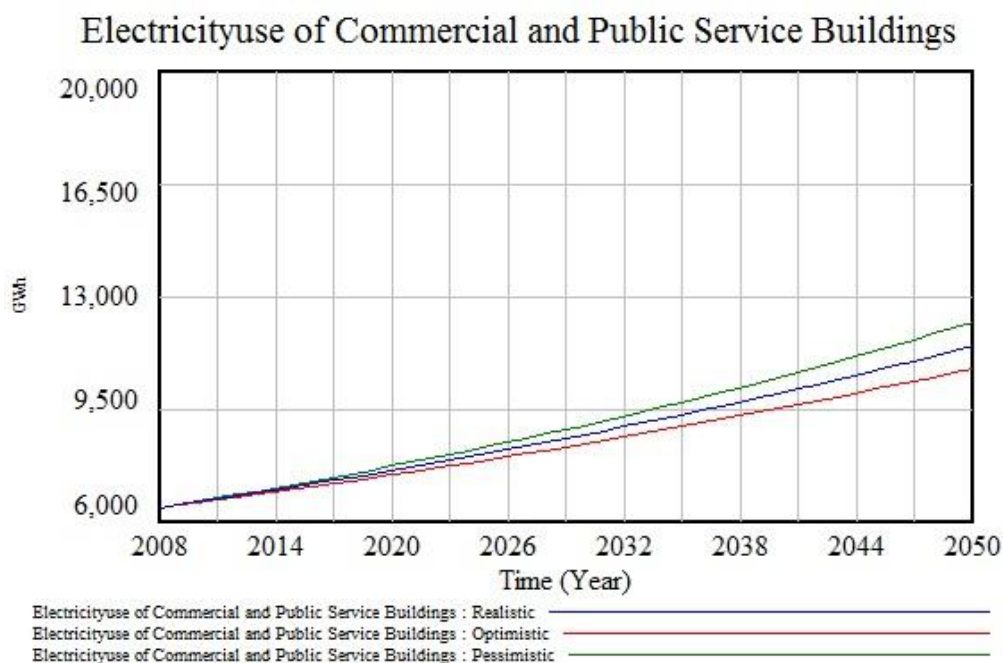


Figure 19: Electricity use of Commercial and Public Service Buildings

Transport Consumption

In the transport sector the realistic, optimistic and pessimistic scenario start at 1,441.12⁶⁸ GWh – increasing to; 1,523.81; 1,512.37; and 1533.31 GWh.

⁶⁶ IEA Electricity/Heat in Romania (2008)

⁶⁷ IEA Electricity/Heat in Romania (2008)

⁶⁸ IEA Electricity/Heat in Romania (2008)

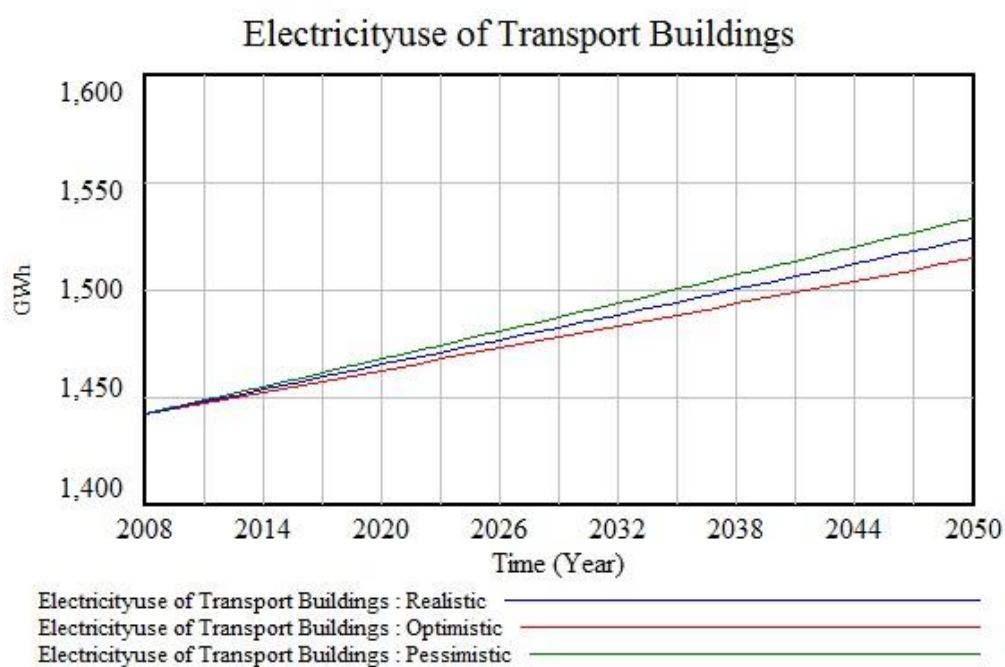


Figure 20: Electricity use of Transport Buildings

Fishing Consumption:

The electricity Fishing Consumption is the lowest consumer for electricity in the model, starting at 1⁶⁹ GWh in 2008 decreasing over 42 years in the realistic scenario (no increasing rate defined) to 0.7 GWh in 2050.

3.2.2.6 Total Electricity Consumption

The aggregation of the sectors above, added up with all imports, exports and losses, lead to the Total electricity Consumption.

Losses	7,190 GWh
Exports	-5,169 GWh
Imports	921 Gwh
Electricity Industry Own Use	10,937 GWh
Statistical Differences	-768 GWh ⁷⁰

Table 6: Statistical Data⁷¹

⁶⁹ IEA Electricity/Heat in Romania (2008)

⁷⁰ IEA Electricity/Heat in Romania (2008)

⁷¹ IEA Electricity/Heat in Romania (2008)

It is assumed that the data in the table above are constant over the planning horizon, as no comparable data for future events were available.

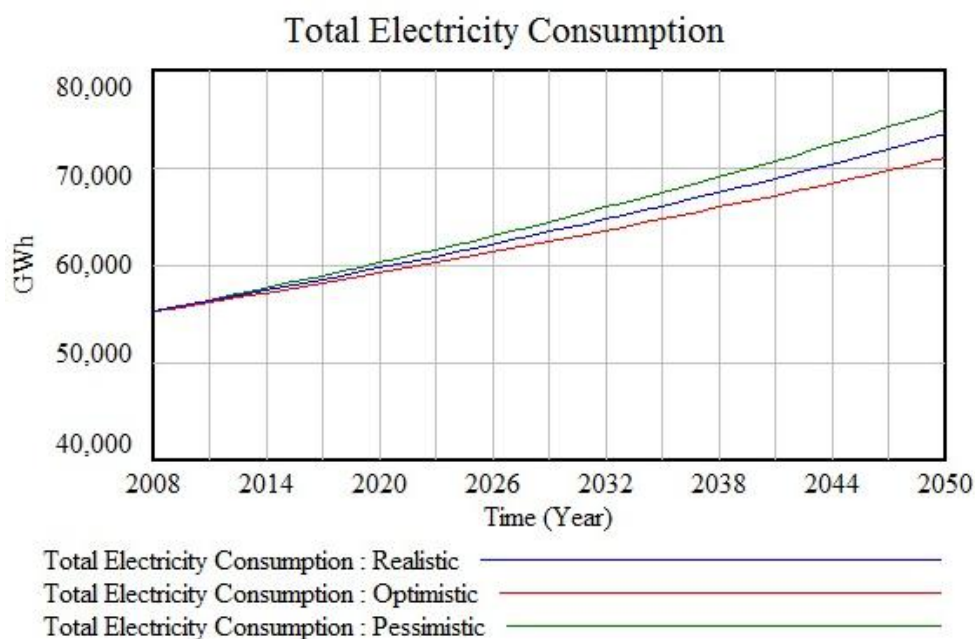


Figure 21: Total Electricity Consumption

The total consumption starts at 55,201.9⁷² GWh in the year 2008 increasing in the realistic scenario up to 73,411.2 GWh, in the optimistic scenario up to 71,002.9 GWh and in the pessimistic scenario up to 75,927.9 GWh in the year 2050.

3.2.3 Comparable Models

Another model to estimate the electricity consumption was published by SUSPlan. Susplan (Planning for Sustainability) is a European project to investigate the integration strategies for renewable source technologies and its grid infrastructure on long term bases. This case study not only implies renewable source development strategies, it rather deals with the current infrastructure needs such as electricity, heat and gas. To determine the future electricity consumption, Susplan developed four different scenarios, called storylines⁷³.

⁷² IEA Electricity/Heat in Romania (2008)

⁷³ SUSPlan (2010 P. 6)

In the Green storyline the consumption of energy is low, because consumers act environmentally friendly. The use of electricity saving measures is widely spread and unnecessary consumption is extensively avoided⁷⁴.

The Yellow storyline: The concern for the environment is among the consumers popular, which has a positive impact on the reduction of energy demand. The limitation of “breakthroughs” in the technology prevent from a further reducing measures⁷⁵.

The Red storyline shows a low awareness for environmental concerns and a poor understanding for the usage of energy saving technologies. Energy demand is constantly high and changes in consumers’ habits among energy consumption are limited.⁷⁶

The Blue storyline is the result of low environmental concerning. Even though the energy saving technology exists (same as in Green Storyline),no efforts are done to lower energy consumption. The reason for this little understanding is the political driven assumption to keep energy prices low – and therefore the need to install technologies is not given.⁷⁷

Year	2010	2020	2030	2040	2050
Green	56.0	71.8	75.0	76.6	76.4
Yellow	56.0	75.0	80.9	84.2	84.8
Red	56.0	84.6	98.6	107.0	110.1
Blue	56.0	87.8	104.4	114.6	118.6

Table 7: Storylines by SUSPlan⁷⁸

In comparison to the demand model presented, in this master thesis, the Green Storyline is more or less similar to Pessimistic Scenario, while the Green scenario deviates from the Realistic Scenario with about 3,000 GWh in the year 2050.

⁷⁴ SUSPlan (2010 P. 6)

⁷⁵ SUSPlan (2010 P. 7)

⁷⁶ SUSPlan (2010 P. 7)

⁷⁷ SUSPlan (2010 P. 8)

⁷⁸ SUSPlan (2010 P. 8)

4 ELECTRICITY MARKET AND MERIT ORDER

4.1 Description of the Romanian Electricity Market

In the 1990s institutional, regulatory and structural reforms were made to deregulate the Romanian power market with the objective to increase quality of services and heighten efficiency. The philosophy of opening the national economy is the free movement of public goods and services, to integrate the Romanian electricity market into a transnational European market by losing its traditional borders.⁷⁹

Timeline of opening the electricity market:

	01.01.2003	31.12.2003	31.12.2004	31.06.2006	01.01.2007
Electricity	33%	40%	55%	80%	100% ⁸⁰

The Romanian competitive market consists out of:

- Bilateral free negotiated contracts – between the producers/suppliers and consumers in the fully open market. Distribution companies have the possibility to trade electricity directly and freely by negotiation or by trading them on the spot market
- Transaction on day ahead market
- Export contracts; negotiation of contracts with foreign consumers
- Network use: Access for third parties use to transmit and distribute electricity with related tariffs⁸¹

4.1.1 Power Exchange by the Market Operator OPCOM

The trading volume achieved on the Day-Ahead market was 5.2 TWh (593 MWh) in 2008, which is an increase of 3% of the previous year. During the year, the interest on trading on the spot market remained constant. The average number of daily active trading counted 55 participants, which is 6% higher than 2007. The trade in hourly intervals was made in volumes starting 158 MWh up to 1,143 MWh

⁷⁹Ministry of Economy and Commerce Romania (2003 p. 13)

⁸⁰Ministry of Economy and Commerce Romania (2003 p. 18)

⁸¹Ministry of Economy and Commerce Romania (2003 p. 12)

according to the participants' possibilities. The average price paid was 51.21 Euro/MWh, concluding in a total amount of all trades in 272.8 million Euros.⁸²

The centralised market for bilateral contracts (through public auction) reached a trading volume of 11.5 TWh in 2008. 97 bilateral contracts (greater than one month) were concluded, having deliveries in 2008 and 2009. 8.6 TWh of the deliveries in 2008 represents 15.7% of the electricity consumption at an average price of 47.4 Euro/MWh.⁸³

In the centralised market for bilateral contracts with continuous negotiation 165 standard contracts of at least 1 MW were traded in weekly or monthly terms. The total trade volume was 36,360 GWh, corresponding to an average price of 55.6 Euro/MWh.⁸⁴

4.2 Estimation of the Energy Mix by a Merit Order

In the literature the marginal cost curve for electricity production is defined as merit order. On its basis the optimal choice of the cost efficient power production to cover given electricity demand, can be investigated at any time⁸⁵.

As a result of the liberalization, companies invest more and more in cost efficient power plants to be competitive on the power market. The utilization of various power station sources (coal, gas, hydro etc.) is driven by the realizable prices on the market. The price development mechanism on the stock market decides in the end the most cost efficient power plant.⁸⁶

4.2.1 Merit Order and the Price Development on the Exchange Market

OPCOM organizes auctions in the Day-Ahead Market to buy electricity deliveries for every hour on the following day. In the next graph the selling bids and the

⁸² Opcom (2008, p. 10)

⁸³ Opcom (2008, p. 10)

⁸⁴ Opcom (2008, p. 10)

⁸⁵ Roon & Huck (2010 p 1)

⁸⁶ Roon & Huck (2010 p 2)

buying bids are sorted corresponding to the height of the price. The interaction of these two curves finally set the traded quantity as well as the price⁸⁷.

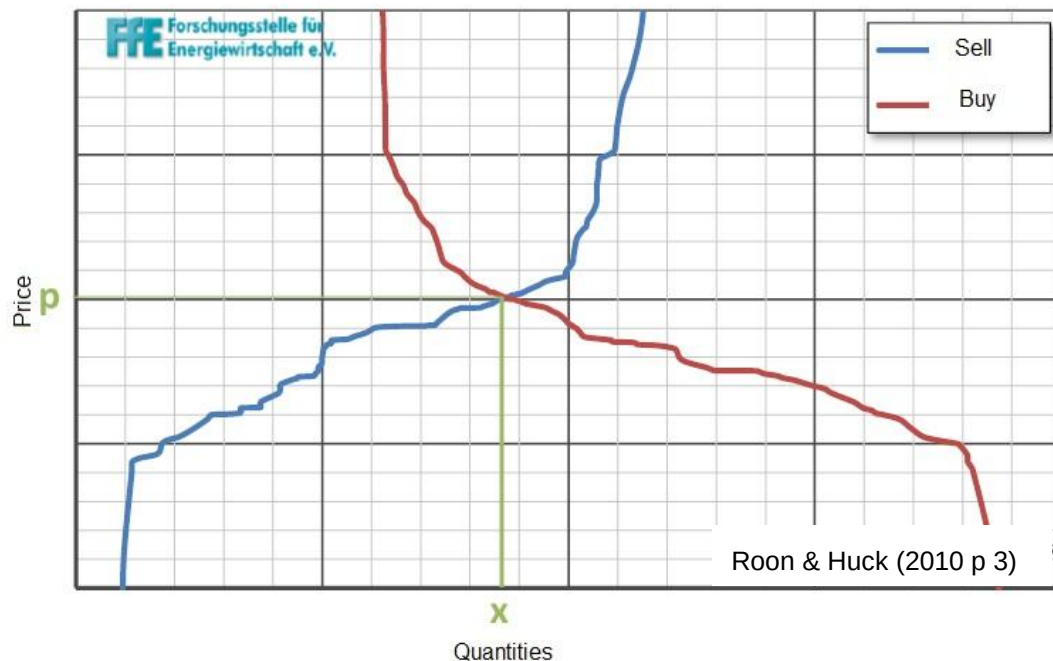


Figure 22: Possible Pricedevlopment at Opcom

Important to mention is that all successfully set bids have to pay or get the same price (market clearing price). All market participants set the heights of their bids according to the marginal costs, because in case of acceptance the price is mostly higher and the possibility to reach a variable gross margin is given. The Day-Ahead Market however is not used for all transaction – it is mostly – as already mentioned above – an adjustment tool for bilateral long term contracts.⁸⁸

To establish a merit order for Romania it is essential to investigate the power plant park. The type of power plants (coal, nuclear, gas and oil) as well as the installed capacity of the Romanian power plant is listed in the appendix.

The merit order model in this study considers only conventional power stations, which use non regenerative primary energy sources.

⁸⁷ Roon & Huck (2010 p 3)

⁸⁸ Roon & Huck (2010 p 3)

4.2.2 Calculation of the Merit Order

To calculate the merit order, it is necessary to allocate the marginal costs to each type of power station. The marginal costs in this case study are approximated by the sum of the primary fuel market price and the tons of CO₂ emitted per megawatt hour multiplied with the costs of the CO₂ permit.

Marginal Costs.... V_i whereby i is the type of power station and α is the efficiency of the power station

$$V_i = \frac{((fuel\ price/MWh) + (CO_2/MWh) * price\ of\ CO_2\ Permit)}{\alpha_i}$$

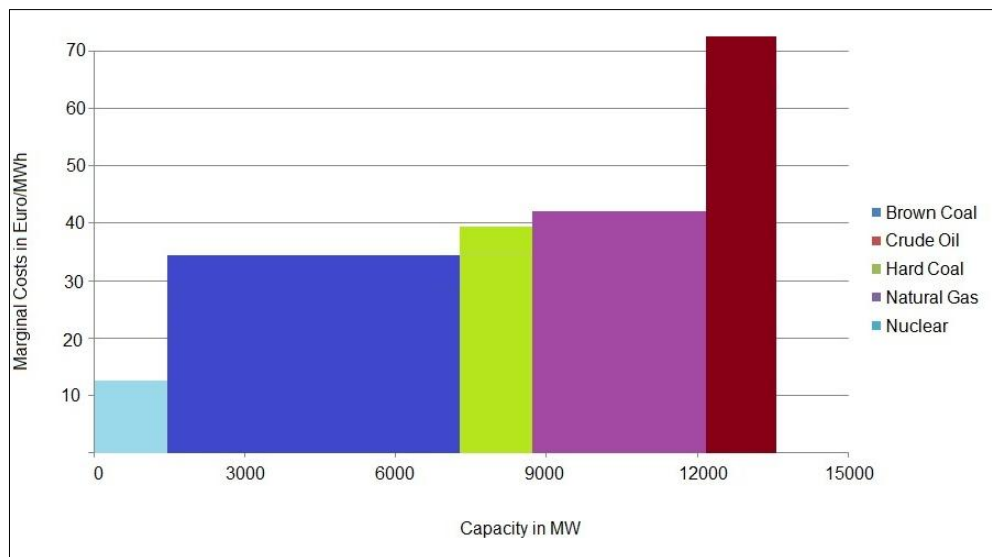


Figure 23: Merit Order of the year 2009

Typical for the merit order figure is the arrangement of power station types corresponding to its marginal costs over the cumulative installed capacity. The figure above shows the price on the market in relation to the demand from the installed capacity.

4.2.3 Merit Order Effect

The Merit order effect is based on a shift of the residual demand curve for electricity to meet the electrical consumption at the lowest wholesale electricity price⁸⁹. Decisions for new installations in the power plant parks to cover electricity

⁸⁹ Wissen & Nicolosi (2007, p. 2)

demand are made due to the estimation of variable costs. In other words, this means that power production units with cost efficient production methods (such as wind and hydropower) can significantly lower the spot market price for electricity⁹⁰. The increase of renewable sources into the power plant park will as result reduce the demand for conventional power stations such as gas-, oil-, and coal fired plants.

Through feeding the power market with electricity produced from renewable sources, the demand for traditional electricity production in the wholesale market will decrease (visible in the figure below) from N_1 to N_2 . Assuming an inelastic supply curve A_1 in 2008 the reduced residual demand for conventional produced electricity results in a lower wholesale prices. According to Sensfuß and Ragwitz the difference in between the price levels is the so called Merit Order Effect⁹¹.

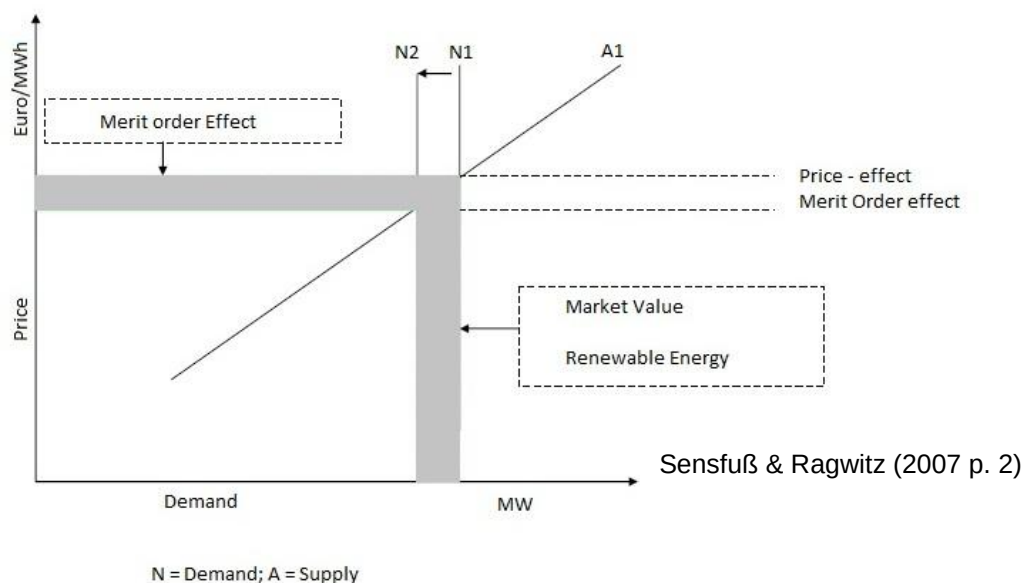


Figure 24: Merit Order Effect (without dynamic effects)

⁹⁰ Mendonca, Jacobs, Sovacool (2009, p.83)

⁹¹ Sensfuß & Ragwitz (2007 p. 2)

5 DATA COLLECTION FOR THE LINEAR PROGRAMMING MODEL

To forecast the future electricity park in Romania a linear programming model was developed. This linear program indicates the changes in the electricity mix over the same time horizon as the prediction of the electricity demand. The main focus in section is on the political overall condition; the future fuel market prices, the CO₂ certificate prices and the technical-economic characterization of future electricity sources as well as power plant related data, such as life time and installation time and ramp up times are discussed. The collected data presented in this section, are the fundament of the in section 6 explained linear programming model. The price scenarios presented in this section originate from various sources, whereas a study, published by the Fraunhofer Institut (Nitsch, Pregger & Scholz: 2010) provides the basis for the almost all price scenarios (all fuel and CO₂ price scenarios expect for nuclear prices).

5.1 Political Overall Condition

The unsatisfying end of the negotiations at the climate conference in Copenhagen in December 2009 prevent from further measures to strengthen and broaden the climate protection. However, climate protection is and remains a significant topic in daily politics and challenges electricity providers and politicians equally. The type of future power plants as well as energy intensity keeps playing a major role in global climate politics and will have a further influence on the development of energy markets and on the international energy politics. If additional pro climate protection steps are taken, carbonic fuel, as a consequence will increase in price⁹².

To this feedback it is understandable that most European nations form programs and legislations to change their electricity policy towards electricity production out of renewable sources. Government's efforts tend to increase renewable sources by simultaneously increasing the efficient electricity use. A differentiated

⁹² Nitsch, Pregger & Scholz (2010, p.4)

consideration among European nations in fields of CO₂ reduction policies and nuclear electricity production exist.⁹³

In connection with the emission reduction the primary energy consumption should be lowered by 20%, whereas the efficiency in traffic, on buildings and electronically advices is increased. National laws are responsible for an inclining power generation of renewable sources. At present the strived share for renewable electricity production in the European average is at 20% for 2020 of the gross energy consumption.⁹⁴

Romania adopted all relevant directives from the European Union in fields of renewable electricity production into its regulatory framework.

“Law No.220/2008 regarding the establishment of a system to promote electricity generation from renewable energy sources (“Law 220/2008) aims at improving the existing system based o so-called green certificates (“GCs”) and sets a target for gross domestic consumption of electricity from renewable energy source at the following levels:”

- 33% for 2010
- 35% for 2015
- 38% for 2020⁹⁵

5.2 Assumption of Future Energy Prices

The crude oil price is characterised by several heavy jumps in the past years, nevertheless an average increasing tendency is ascertainable. During the decade 1990 to 2000 a crude oil price was stated as cheap when it reached a price of 20\$/b, today a price of 60\$/b is regarded as extremely cheap. After a short decline

⁹³ Nitsch, Pregger & Scholz (2010, p.4)

⁹⁴ Nitsch, Pregger & Scholz (2010, p.5)

⁹⁵ Wolf Theiss (2010, p. 146)

to 60€₂₀₀₇/b (on a year average) the crude oil price increased in 2010 to 80\$/b⁹⁶.

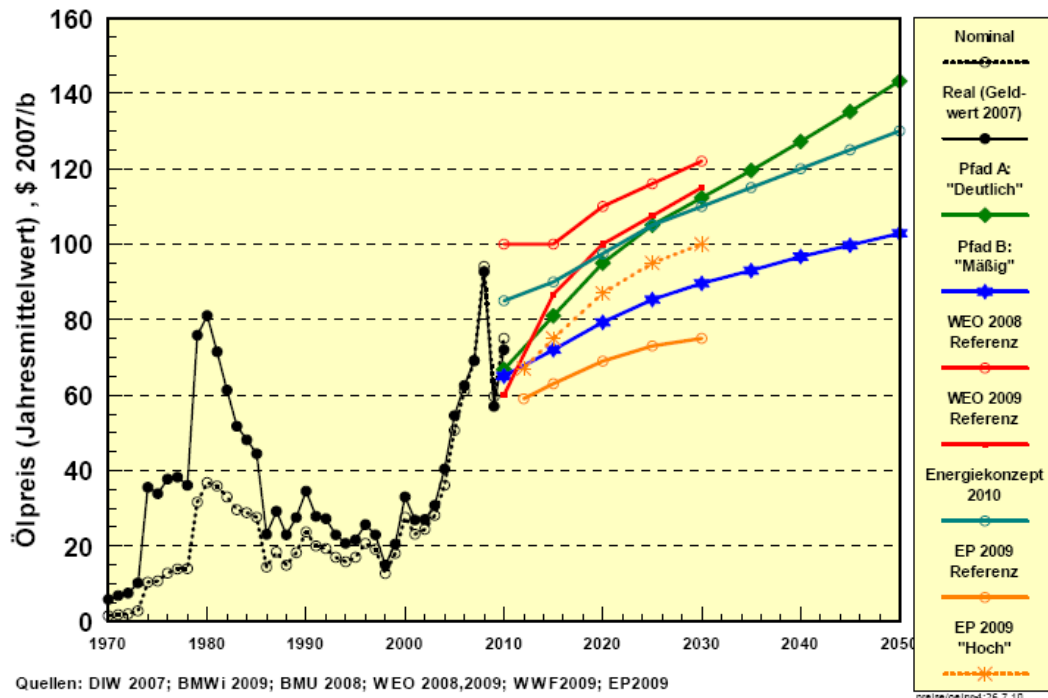


Figure 25: Crude Oil Price Development 1970 - 2010 and Price forecasts

In the graph above the crude oil price of the past, as well as the forecasts for the future development is shown. The German “Fraunhofer Institut calculates for the German Bundesministerium für Wirtschaft und Technologie, two possible future scenarios. The bases are the World Energy Outlook crude oil predictions investigated by the International Energy Agency and the “Energiepreisprognose 2009” established by the German Government. The green line (Preispfad A Deutlich, in the graph above) corresponds until the year 2030 with the WEO 2009 reference, whereas the WEO assumption for crude oil in 2008 was even higher. The turquoise line (Energiekonzept) reveals a similar price in the period from 2020 to 2030, but the end price in 2050 is slightly lower than the green line (Pfad A Deutlich). According to the Fraunhofer Institut the green line is the basic assumption of the future crude oil price, while the blue line (Pfad B Mäßig) expects a clearly lower oil price development. Additionally to the existing pricing scenario a

⁹⁶ Nitsch, Pregger & Scholz (2010, p.17)

third one was developed by the Fraunhofer Institut in 2004, which was also considered in the forecast⁹⁷.

The height of the cross-border-prices depends on the development of the exchange rate (\$/€) and on the development of the crude oil price. The natural gas and the coal price are linked closely to the height of the oil price reflected by the dominance of the crude oil price in the energy sector. As visible in the table below the natural gas and coal price incline due to oil price upward jumps⁹⁸.

real. €2008/MWh	2008	2009	2010	2020	2030	2040	2050
Pfad A: „Deutlich“							
Crude oil	41.04	26.64	31.32	47.52	58.68	69.12	78.48
Natural Gas	26.28	20.52	24.12	38.52	49.68	59.76	69.12
Hard Coal	13.68	10.44	11.16	18.36	23.40	28.44	33.12
Lignite	5.89	5.89	6.44	11.97	17.51	23.04	28.57
Pfad B: „Mäßig“							
Crude oil	41.04	26.64	30.24	38.52	46.80	52.56	56.52
Natural Gas	26.28	20.52	23.40	30.60	37.08	41.76	44.64
Hard Coal	13.68	10.44	10.80	14.40	16.92	18.36	19.80
Lignite	5.89	5.89	6.12	8.40	10.68	12.97	15.25
Pfad C: „Sehr niedrig“							
Crude oil	41.04	26.64	27.00	29.52	32.76	35.64	37.44
Natural Gas	26.28	20.52	21.60	23.40	26.28	28.44	29.88
Hard Coal	13.68	10.44	10.80	11.88	13.32	14.04	15.12
Lignite	5.89	5.89	6.00	7.15	8.29	9.43	10.57 ⁹⁹

Table 8: Fossil Resource Price Predictions¹⁰⁰

⁹⁷ Nitsch, Pregger & Scholz (2010, p.18)

⁹⁸ Nitsch, Pregger & Scholz (2010, p.18)

⁹⁹ Nitsch, Pregger & Scholz (2010, p.19)

The development of prices of CO₂ certificates is of high significance and therefore added to the list. The assumptions for CO₂ prices are for:

	2010	2020	2030	2040	2050
Preispfad A	25€	40€	52€	62€	73€
Preispfad B	21€	31€	36€	42€	47€
Preispfad C	16€	21€	24€	27€	29€ ¹⁰¹¹⁰²

Table 9: CO₂ Certificate Price Predictions

If the CO₂ prices are added to the fuel prices, the CO₂ price of i.e. 30€/t heightens the price of natural gas by 1.69€/GJ, crude oil by 2.23€/GJ, hard coal of 2.76€/GJ and lignite of 3.34€/GJ.¹⁰³

In the following table the CO₂ certificate prices are added to the fuel price list above. The CO₂ price, which increases the fuel price is converted to MWh and adjusted to each “Preispfad” of the table CO₂ price assumptions.

real. €2008/MWh	2008	2009	2010	2020	2030	2040	2050
Pfad A: „Deutlich“							
Crude oil	47.73	33.33	38.01	58.22	72.60	85.71	98.01
Natural Gas	31.35	25.59	29.19	46.63	60.23	72.33	83.92
Hard Coal	21.96	18.72	19.44	31.61	40.62	48.97	57.30
Lignite	15.91	15.91	16.46	28.01	38.35	47.89	57.83
Pfad B: „Mäßig“							
Crude oil	46.66	32.26	35.86	46.82	56.43	63.80	69.10
Natural Gas	30.54	24.78	27.66	36.89	44.38	50.28	54.17
Hard Coal	20.64	17.40	17.76	24.67	28.84	32.27	35.37

¹⁰⁰ The incline/decline within the decades is assumed to be linear, as only the decade-price-values were available.

¹⁰¹ It is assumed that the 2007/2008 years data are equal to 2010

¹⁰² Nitsch, Pregger & Scholz (2010, p.19)

¹⁰³ Nitsch, Pregger & Scholz (2010, p.20)

Lignite	14.31	14.31	14.54	20.83	25.11	29.80	34.09
Pfad C: „Sehr niedrig“							
Crude oil	45.32	30.92	31.28	35.14	39.18	42.87	45.20
Natural Gas	29.52	23.76	24.84	27.66	31.15	33.92	35.76
Hard Coal	18.98	15.74	16.10	18.84	21.27	22.98	24.72
Lignite	12.30	12.30	12.42	15.56	17.91	20.25	22.19

Table 10: Fossil Prices + CO₂ Prices

Comparing the new prices (fuel prices + CO₂ prices) with the conventional fuel prices it can be said that the price increase of natural gas is caused by the fuel increase itself: looking now at lignite and hard coal the price increase is mostly caused by the increase of the CO₂ certificate price. This incline of CO₂ certificate prices makes an economic trade of certificates indispensable and creates a new and fair competition concerning the usage of fossil and renewable sources. If CO₂ certificate prices are assumed to be on the same level as 2009, the use of renewable sources will be unprofitable and as a consequence fuel fired power stations keep running¹⁰⁴.

5.3 Future Electricity Production Plants

In the following chapter an overview over the techno-economic status and a expected future development of fossil and renewable sources is given. The data described in this section are taken from the Fraunhofer Institut and in case expended or simply adopted. The Fraunhofer Institut overtook data from the EU Project NEEDS (New Energy Externalities Development for Sustainability 2009)), from the IEA (2010) and from the European umbrella organisation for renewable energy (EREC 2010).¹⁰⁵

¹⁰⁴ Nitsch, Pregger & Scholz (2010, p.20)

¹⁰⁵ Nitsch, Pregger & Scholz (2010, p.21)

5.3.1 Photovoltaic

The photovoltaic market developed itself dynamically over the last two decades. The technique for photovoltaic used at the moment is dominated by mono crystalline and poly crystalline solar cells as well as thin film cells out of amorphous silicon. Future thin film technology consists out of gallium arsenide, germanium, cadmium-telluride and copper –indium diselenid. New production techniques enable lower material input and losses and a further increases in production volumes on the basis of silicon solar cells. It is expected that these cells allow significant module-cost reductions and a higher efficiency performance in the future¹⁰⁶. At the moment there is no considerable photovoltaic power plant installed and therefore no capacity in the Romanian electricity generating market¹⁰⁷.

5.3.2 Windpower Onshore

Likewise developing was the market for wind power onshore power plants in the last years. The installed capacity in Romania increased from 1 MW in 2002 to 8 MW in 2007 and finally to 14 MW in 2009. Several new onshore wind parks are under construction and will be completely built up in the upcoming years. The approved - not yet finished wind parks - will generate 448 MW additionally¹⁰⁸.

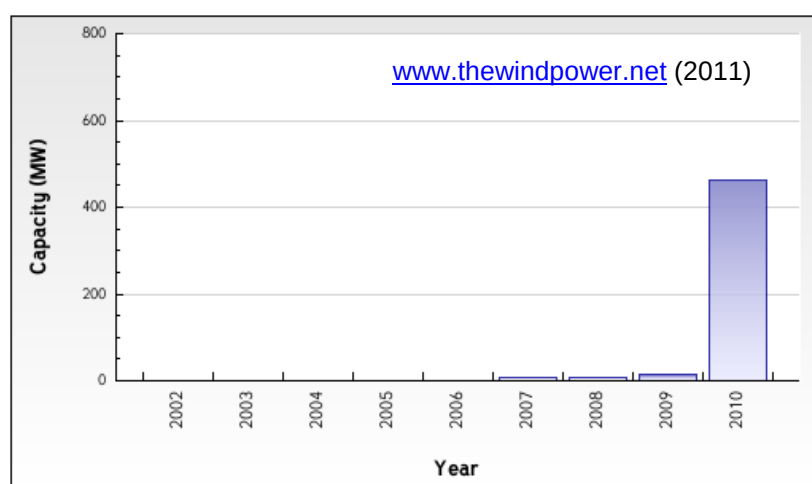


Figure 26: Development of Wind Power Capacities

¹⁰⁶ Nitsch, Pregger & Scholz (2010, p.22)

¹⁰⁷ IEA Energy Balance for Romania (2008)

¹⁰⁸ TheWindPower (2011)

Modern wind power stations reach, due to the buoyant principle, a degree of an efficiency of about 50%. The technical development of wind power plants tend to bigger constructions, changing from < 50kW in 1987 to 1.9 MW in 2009, to use locations optimally.

5.3.3 Windpower Offshore

Since the wind power offshore market is rather new, missing experience leads to higher initial costs. In 2009 there were no wind power offshore farms built in Romania. The worldwide average water depth of new plants was about eleven meters below sea level in 2009, while the new level for new plants is about 27 meters below SL. The middling distance from shore was 13 km in 2009, for plants under construction it is more than 28 km¹⁰⁹.

In comparison to installed onshore capacity, offshore generates up to 40% more power per installed capacity, due to constant and stronger wind resource. Until now, only 5 MW power plants were constructed, but plant performances of 15 MW with longer rotor blades and greater hub heights are thoroughly conceivable. As a result cost reductions through better high sea machinery, advanced installation methods and a close grid connection are possible in Romania. The possible future installed capacity is according to SUSPlan 1750 MW¹¹⁰.

5.3.4 Hydro Power

At present 113 hydro power stations with an installed capacity of 6,400 MW produce about 17,195 GWh annually, which is a share of 27%¹¹¹. The potential for hydro power is still not completely exhausted. According to Popa and Popa the future maximum of installed capacity is 9,300 MW¹¹².

5.3.5 Concentrating Solar-Thermal Power Plants The Model (CSP)

The CSP does not play an important role in the Romanian electricity generating market and will not be installed in the upcoming years. Until 2020 PNEAR (Planul

¹⁰⁹ Nitsch, Pregger & Scholz (2010, p.23)

¹¹⁰ Nitsch, Pregger & Scholz (2010, p.23)

¹¹¹ IEA Energy Balance for Romania (2008)

¹¹² Popa & Popa (2008, P.11)

Național de Acțiune în Domeniul Energiei din Surse Regenerabile) predicts on commercial use of CSP and on this account it assumed that a further electricity production is excluded¹¹³.

5.3.6 Geothermal Energy

The geothermal electricity production is very new to the existing power plant market. At present there is no geothermal plant under construction or even planned in Romania. Geothermal electricity will not be installed for commercial electricity production in foreseeable periods¹¹⁴¹¹⁵.

5.3.7 Biomass

The installed capacity for Biomass was in 2009 zero MW, whereas an increase in the upcoming years seems realistic. As a base for this electricity generation system forest wood and waste wood is used as fuel to operate a biomass power station, which possibly can reach up to 20 MW. In today's plants the biomass is burned to power steam turbines. For future smaller plants with lower performance (< 1 MW) a Stirling engine as generator is in discussion, to compete with an acceptable electrical efficiency. For bigger plants (> 1 MW), the gasification of biomass and the usage of cogeneration units, gas turbines or gas- and steam turbine plants, promise higher efficiency.¹¹⁶

Cogeneration units exist in different performance categories. The ranges of power plants start with a few kW of an electrical utilization level of 25% as well as in the MW area of an electrical efficiency level up to 40%.

5.3.8 Biogas

Biogas is mostly used as a power heat coupling plants, starting with a few kW up to several MW. The degree of efficiency reaches thereby 25% to 40%, which is more or less the same as for Biomass power plants.

¹¹³ Nitsch, Pregger & Scholz (2010, p.24)

¹¹⁴ IEA Energy Balance for Romania (2008)

¹¹⁵ PNAER (2010 p.201-202)

¹¹⁶ Nitsch, Pregger & Scholz (2010, p.24-25)

Plant oil is mostly used in cogeneration units; the size of the plant depends on its usage, ranging from domestic use with just a few kW up to power plants in the MW area for commercial power production. As fuel rapeseed oil or palm oil is inserted. The electrical utilisation of plant oil cogeneration units reaches values comparable with the Biomass plants.¹¹⁷

5.3.9 Fossil Electricity Generation

The technological assessment for fossil fired power plants is difficult, because new techniques are developed at regular intervals. New technological acquisitions (i.e. Carbon Dioxide Capture and Storage) make a forecast almost impossible. Unclear is, how far fossil electricity generation play a role in future generation mixes. The list below nevertheless shows a possible development of changes in efficiency and CO₂ emissions.¹¹⁸

5.3.10 Nuclear power Plants

Nuclear power is described as a bridging technology. According to Hobohm et al. it reaches an electrical efficiency of 40%¹¹⁹ and is completely emission free. The major problem of nuclear power is the final deposit of the hazardous nuclear waste and in cases of catastrophes the lack of controllability.

5.3.11 Powerplant Specific Data

Fixed Costs/Year (in Thousands Euro)	2009	2010	2020	2030	2040	2050
PV	3,151	2,729	1,203	994	937	903
Windpower Onshore	1,320	1,320	1,030	980	940	900
Windpower Offshore	3,500	3,300	2,100	1,800	1,500	1,300
Hydropower	2,730	2,730	2,961	3,182	3,323	3,497
CSP	4,628	4,628	3,435	2,813	2,599	2,505

¹¹⁷ Nitsch, Pregger & Scholz (2010, p.25)

¹¹⁸ Nitsch, Pregger & Scholz (2010, p.27)

¹¹⁹ Hobohm, Koepp, Peter, Arndt & Steden (2005, p. 21)

Geothermal	12,500	12,350	10,458	9,310	8,375	7,275
Biomass	3,405	3,408	3,327	3,333	3,281	3,196
Biogas	3,616	3,584	3,211	3,080	2,950	2,858
Hard Coal	1,300	1,300	1,300	1,300	1,300	1,300
Lignite	1,100	1,100	1,100	1,100	1,100	1,100
Natural Gas	700	700	700	700	700	700
Crude Oil	1,100 ¹²⁰	1,100	1,100	1,100	1,100	1,100
Nuclear Power	1,350	1,350	1,350	1,350	1,350	1,350

Table 11: Fixed Cost/ Technology¹²¹

Variable Costs/Year Mäßig¹²²	2009	2010	2020	2030	2040	2050
PV	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0
CSP	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Biomass	20.16	20.88	23.04	24.12	25.92	28.08
Biogas	21.60	21.60	25.56	26.28	26.64	27.00
Hard Coal	17.40	17.76	24.67	28.84	32.27	35.37
Lignite	14.31	14.54	20.83	25.11	29.80	34.09
Natural Gas	24.78	27.66	36.89	44.38	50.28	54.17

¹²⁰ Assumed to be same as lignite

¹²¹ Nitsch, Pregger & Scholz (2010, p.27)

¹²² The other scenarios are shown in the Appendix

Crude Oil	32.26	35.86	46.82	56.43	63.80	69.10
Nuclear Power	4.80	4.80	4.90	5.70	7.10	9.10

Table 12: Variable Costs / Technology

Efficiency/Year	2009	2010	2020	2030	2040	2050
PV	0.81	0.81	0.82	0.83	0.84	0.85
Windpower Onshore	0.23	0.23	0.25	0.27	0.28	0.29
Windpower Offshore	0.37	0.37	0.42	0.43	0.44	0.45
Hydropower	0.63	0.63	0.63	0.63	0.64	0.64
CSP - solarthermal Powerstation	0.74	0.74	0.74	0.74	0.74	0.74
Geothermal	0.70	0.70	0.73	0.75	0.76	0.76
Biomass	0.80	0.80	0.79	0.78	0.77	0.77
Biogas	0.38	0.38	0.39	0.40	0.40	0.41
Hard Coal	0.46	0.46	0.50	0.51	0.51	0.51
Lignite	0.43	0.43	0.47	0.49	0.49	0.49
Natural Gas	0.58	0.58	0.60	0.62	0.62	0.62
Crude Oil	0.43 ¹²³	0.43	0.47	0.49	0.49	0.49
Nuclear Power	0.40	0.40	0.40	0.40	0.40	0.40 ¹²⁴

Table 13: Efficiency/ Year¹²⁵

¹²³ Assumed to be same as lignite

¹²⁴ Hobohm & Koepp, et al (2005) S.24

¹²⁵ Nitsch, Pregger & Scholz (2010, p.25ff)

CapacityMax/Year	2009	2010	2020	2030	2040	2050
PV	0	0	260	460	660	860
Windpower Onshore	9.26	462	4,000	5,100	6,200	7,300
Windpower Offshore	0	0	0	583	1,167	1,750
Hydropower	6,400	6,500	7,729	8,253	8,776	9,300 ¹²⁶
CSP - solarthermal Powerstation	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0
Biomass	0	14	600	800	1,000	1,200
Biogas	0	4	195	230	265	300
Hard Coal	1,900	1,900	1,900	1,900	1,900	1,900
Lignite	5,700	5,700	5,700	5,700	5,700	5,700
Natural Gas	3,435	3,435	3,435	3,435	3,435	3,435
Crude Oil	1,519	1,519	1,519	1,519	1,519	1,519
Nuclear Power	1,412	1,412	1,412	1,412	1,412	1,412

Table 14: CapacityMax/ Technology¹²⁷¹²⁸

¹²⁶ Popa & Popa (2008, P.11) increases linear over time

¹²⁷ PNAER (2010 p.201-202)

¹²⁸ It is assumed that thermal power stays at the present status quo

Technology	Lifetime (Years)	Installation Time (Years)	Ramp UP Time
PV	25	1	1
Windpower Onshore	25	2	1
Windpower Offshore	20	2	1
Hydropower	40	2	1
CSP	20	1	1
Geothermal	25	1	1
Biomass	25	5	0.1
Biogas	25	5	1
Hard Coal	35	4	0.05
Lignite	35	4	0.05
Natural Gas	25	4	0.2
Crude Oil ¹²⁹	35	4	0.5
Nuclear Power	40	5	0.05

Table 15: Power Plants Related Data¹³⁰¹³¹¹³²¹³³

¹²⁹ Assumed to be same as lignite

¹³⁰ Ramp Up Time is assumed

¹³¹ Kaltschmidt, Streicher (2009) 59ff

¹³² Installation Time: Hard Coal, Lignite, Natural Gas, Nuclear Power: Hobohm & Koepp, et al (2005) S.15

¹³³ Lifetime: Hard Coal, Lignite, Natural Gas, Nuclear Power: Hobohm & Koepp, et al (2005) S.15

6 THE LINEAR PROGRAMMING PROBLEM

In the following section the developed linear programming problem will be explained in detail to forecast the future Romanian electricity mix,. The calculation of the LP problem is based on a model, provided by the University of Vienna and adjusted by the author. The used data (such as variable costs, fixed costs and efficiency data) are on a yearly basis completely shown in the Appendix. The decade data from chapter 5.3.11 Power Plant Specific Data are presented to give an impression of the changes over the planning horizon. To compute the linear program a tool on the Cplex solver technique, provided by IBM is used. A change in the starting year – the so called base year is necessary. The starting point of the provided data from the Fraunhofer Institut differ to the starting point of the demand forecast model. The change in the base year (demand forecast model 2008 und linear programming model 2009) arises due to a lack of availability of current data of the demand structure presented by the IEA. The latest available data of the IEA balances are from the year 2008, while fuel price data and CO₂ certificate data forecasts start in the year 2009. To create a contemporary energy mix prediction the newest available data of fuel prices and CO₂ certificate costs (2009) as well as demand data from the IEA (2008) are used and adopted in the linear programming model. As a consequence, and further to avoid inconsistencies the demand forecast used in the model starts at 2009.

6.1 Description of the Linear Programming Model

To model the new electricity production mix of Romania in the upcoming years a linear programming problem was formulated. At first it is considered that the electricity demand of the base year 2009 is divided into $S \in \mathbb{N}$ different typical periods, which should resemble a week per season¹³⁴. For simplicity reasons the year is split into four typical weeks, such as one winter week, one spring week, one summer week and one autumn week – the so called periods. The periods of demand are split into hours (totally 168 h) to consider the peak and off-peak times during a day. Each period is multiplied with n_s , which is the amount of period per season to finally reconstruct a year.

¹³⁴ The electricity consumption differentiates by each hour per day and per week

As shown in section 3.2.2.6 (Total Electricity Consumption) the electricity demand increases over the planning horizon. To calculate the expansion of the yearly demand the website www.entsoe.eu is used. The latter offers all electricity consumption data of the last periods, displaying electricity data of daily and hourly demand. The 2008 consumption data are taken und multiplied with the constant factor of each year to fulfil the modelling requirements. This constant factor presents the incline of the total electricity consumption over the planning horizon and is calculated by $\frac{\text{Total Electricity Consumption (M)}_t}{\text{Total Electricity Consumption (M)}_0}$. The new demand is scaled therefore in the typical week or hour up or down by this constant factor. Where it starts in 2009 at the value 1.00642 rising over time to a maximum of 1.32987. The result leads to the hourly electricity consumption within periods over the total planning horizon starting from 2009 to 2050, expressed following:

$$D(t, s, h)$$

Where, $t = \text{year}$, $s = \text{period}$ and $h = \text{hours}$;

	2009	2010	2011	2012	2013	2014
Annual consump.	55556.3	55914	56275	56639.5	57007.5	57378.9
Increase	1.0064	1.0129	1.0194	1.0260	1.0327	1.0394
	2015	2016	2017	2018	2019	2020
Annual consump.	57753.9	58132.4	58514.6	58900.3	59289.8	59683
Annual increase	1.0462	1.0531	1.0600	1.0670	1.0741	1.0812
	2021	2022	2023	2024	2025	2026
Annual consump.	60079.9	60480.6	60885.1	61293.5	61705.8	62122.1
Annual increase	1.0884	1.0956	1.1030	1.1104	1.1178	1.1254
	2027	2028	2029	2030	2031	2032
Annual consump.	62542.3	62966.6	63395	63827.5	64264.1	64704.9
Annual increase	1.1330	1.1407	1.1484	1.1563	1.1642	1.1721

	2033	2034	2035	2036	2037	2038
Annual consump.	65150.00	65599.4	66053.1	66511.2	66973.7	67440.7
Annual increase	1.1802	1.1884	1.1966	1.2049	1.2132	1.2217
	2039	2040	2041	2042	2043	2044
Annual consump.	67912.2	68388.3	68869	69354.4	69844.5	70339.3
Annual increase	1.2303	1.2389	1.2476	1.2564	1.2653	1.2742
	2045	2046	2047	2048	2049	2050
Annual consump.	70839	71343.5	71852.90	72367.30	72886.70	73411.2
Annual increase	1.2833	1.2924	1.3016	1.3110	1.3204	1.3299

Table 16: Increase of the Constant Factor

It is further assumed that electricity is traded in a competitive market with perfectly inelastic demand. The elasticity equals zero, because it is supposed that the demand habit does not change although the prices increase over time¹³⁵.

The author supposes that the market consists of a small number of suppliers with a large number of buyers. An influence of price settings and price fitting measures through the suppliers is not possible due to the existence of the market control by the Opcom. The market price for electricity equals the marginal costs of the most expensive producer, since the market is competitive. All producers are required to meet the electricity demand within the time horizon t .¹³⁶ The efficient production of electricity is still a concern of the big Romanian suppliers. The investment into production facilities with lower marginal costs is therefore a realistic future scenario.

The electricity can be produced in several different technologies $1, \dots, I$. The technology contains already used technology forms such as hydropower, wind power and all fossil fired power plant and new technology power systems like wind

¹³⁵ Mankiw (2011, S.280)

¹³⁶ The time horizon starts in the base year 2009 and lasts until 2050

power offshore and biomass. The list of technology used is visible in section 5.3 Future Electricity Production Plants.

Technology implications:

- The capacities for technology i at time t are denoted by $C_{i,t}$, for all $1 \leq t \leq T$ and $1 \leq i \leq I$.
- The technology i has fixed costs F_i which is in the case of this study the specific investment costs and represent the installation costs/MWh
- Variable costs $\alpha_i V_{i,t}/MWh$, where $\alpha_i \in [0,1]$ is the rate of efficiency of the fuel fired power stations of technology i to produce electric energy. $V_{i,t}$ is the price of the fuel needed by the technology i .

To calculate the linear programming problem several real variables, which are used in the constraints, have to be known.

1. Initial values for the capacities, $C_{i,1}$ for $1 \leq i \leq I$;
2. The efficiencies $\alpha_i \in [0,1]$;
3. The specific investment costs for new capacity F_i per MW for $1 \leq i \leq I$;
4. The demands $D(t,s,h)$ over the whole planning horizon $1 \leq t \leq T$ in MWh;
5. The prices for primary energy $V_{i,t}$ over the planning horizon;
6. The discount rate ρ ;
7. The time needed to install new capacity d_i as well as the lifetime of a plant l_i , for $1 \leq i \leq I$;
8. The maximum capacity for technology i within the planning horizon t ;

To define the demand $D(t,s,h)$ we use M_t and set $D(t,s,h) = D(0,s,h) \frac{M_t}{M_0}$. The prices consist out of the prices for CO₂ certificates and the market prices for primary energy.

$$V_i = \text{market price} + (CO_2/MWh) * \text{price of } CO_2 \text{ Permit}$$

6.1.1 Cost Reduction

To calculate the expansion of the power generating mix of Romania the linear programming problem can be written as:

$$\text{minimize } \sum_{t=1}^T \rho^{-t} \pi_t$$

where ρ^{-t} is the discount rate over the planning horizon. It is assumed that the discount factor is 7.5 percent over the upcoming years. π_t are the costs in year t which should be minimized to get the optimal (feasible) solution. The time frame used in this model and indexed as t (unless otherwise stated), describes the planning horizon from 2009 to 2050.

$$\text{subject to: } \pi_t \geq \sum_s n_s \sum_h \sum_{i=1}^I \frac{V_{i,t} p(t, s, h, i)}{\alpha_t} + \sum_{i=1}^I e_{i,t} F_i \quad \forall t$$

n_s is the sum of all periods, which differs by period. It is assumed that the number of each period is the same; summer or winter seasons do not last longer than spring or autumn. The amount of periods for each season is 13 weeks.

The efficiency denoted as α_t is the optimal utilization of power plants using fossil energy sources to generate electricity. The variable costs are indicated as $V_{i,t}$, which represent the fuel costs (visible in Table 12: Variable Costs / Technology). Also nuclear power has variable costs, which indicate the procurement costs for nuclear fuel. As listed above, it is assumed that no renewable electricity generating source, except for biomass (which has fuel costs but produces CO₂ neutral) has variable costs. Variable costs, such as operational costs, were not respected due to deviating costs for each plant size. The subtraction $\frac{V_{i,t}}{\alpha_t}$ calculates the overall variable costs which accrue at efficient capacity utilization of the power plants.

$e_{i,t}$ and $p(t, s, h, i)$ are decision variables, where $e_{i,t}$ is denoted as the expansion of the capacity in technology i in the time period t . $p(t, s, h, i)$ is the production of electricity in the year t in the representative period s in the hour h generated by the technology i .

6.1.2 Demand Constraint

$$\sum_{i=1}^I p(t, s, h, i) = D(t, s, h) \quad \forall t, \forall s, \forall h$$

The sum of the production in year t in the representative period s in the hour h with the technology i equals the electricity demand of the year t in the period s in the hour h .

6.1.3 Capacity Constraints

$$0 \leq p(t, s, h, i) \leq C_{i,t} \quad \forall i, \forall t$$

where $C_{i,t}$ is the overall technology i in the years t . The production has to be greater than or equal zero over the planning horizon, but it has to be less than or equal to $C_{i,t}$.

$$C_{i,t} \leq CapacityMax_{i,t} \quad \forall i, \forall t$$

The right term of the equation above represents the maximum of possibly reachable capacity within the planning horizon. The $CapacityMax_{i,t}$ describes the possible expansion growth in each year and cannot be exceeded by any technology used.

$$\sum_{i=1}^I e_{i,k} = CapOld_{i,k} \quad \forall i, \forall k: 1980 \leq k \leq 2008$$

where $e_{i,k}$ is the expansion of all used technologies i within the period k from 1980 to the base year 2008. $CapOld_{i,k}$ is the existing capacity of the technology i of this time frame k , which has to be equal to the expansion during this area and is given as a input for the model.

$$C_{i,t} = \sum_{j=1980}^{t-InstallationTime} e_{i,j} - \sum_{j=1980}^{t-LifeTime} e_{i,j} \quad \forall i, \forall t$$

where $C_{i,t}$ is the capacity, which has to be equal to the right term of this equation. The first part of the right term stands for the sum of $e_{i,j}$, which is the expansion of

technology in the time frame from 1980 until 2050. In the years 1980 – 2008 $e_{i,j}$ is given according to the constraint $\sum_{i=1}^I e_{i,k} = CapOld_{i,k}$. The first term ensures that future demand for new capacity is provided according to its actual requirement. This means that the start of construction of new capacity begins before (see Table 15: Power Plants Related Data) the plant is able to generate electricity and dependent on the second term on the equation. If the lifetime of a power plant is expired a new power plant has to be built to meet capacity requirements. The second term of the right equation ensures the further power plant extension after the expiration of lifetime. Within the planning horizon the expansion of technology i can be extended only if the lifetime of the power plants (technology lifetime differentiates, see Table 15: Power Plants Related Data) is fully expired and increasing demand requires additional capacity. The time frame is set equally to the first term so that the existing technology i leaves the future power generating market after its withdrawal. To determine the date of withdrawal, well founded data such as the operation begin of all power stations of technology i and the life time of each technology, are necessary. The operation starts are brought in with the variable $CapOld_{i,k}$ where the development of the electricity generation of the last four decades is listed. The date of withdrawal is identified by the addition of the life time to the year of the operation begin. To avoid conflicts of the life time of technology i , the expansion e_i and the starting date of $CapOld_i$ is denoted with 1980. In cases of a longer technology lifetime (all fossil fired power plants and hydro power stations) of the former capacity (according to the lifetime) is aggregated to the capacity of 1980.

6.1.4 Utilization of Renewable Electricity Sources

Renewable sources have a maximum utilization given due to environmental constraints. Wind power (onshore, offshore), photovoltaic and hydropower are subjected to climatical changes during the year. To enter this conditions in form of mathematical constraints data concerning the wind, water and sun utilization are necessary. The data used are identically taken from the Austrian climate situation, as no comparable data from Romania are found. As no offshore plants exist in Austria, a second possible scenario was taken to demonstrate the wind offshore

market. The randomly generated scenario data for Windpower, PV and Hydropower taken for these four renewable sources and were provided from the University of Vienna.

$$p(t, s, h, \text{Windpower Onshore}) \leq \text{WindProd}(t, s, h) * C_{\text{Windpower Onshore}, t} \quad \forall t, \forall s, \forall h$$

$$\begin{aligned} p(t, s, h, \text{Windpower Offshore}) \\ \leq \text{WindProdOff}(t, s, h) * C_{\text{Windpower Offshore}, t} \end{aligned} \quad \forall t, \forall s, \forall h$$

$$p(t, s, h, \text{PV}) \leq \text{PVProd}(t, s, h) * C_{\text{PV Onshore}, t} \quad \forall t, \forall s, \forall h$$

$$p(t, s, h, \text{Hydropower}) \leq \text{HydroProd}(t, s, h) * C_{\text{Hydropower}, t} \quad \forall t, \forall s, \forall h$$

In cases where the demand is smaller than the utilization of the above stated renewable sources the productivity capacity is not fully used and therefore the production has to be less in this time intervals.

6.1.5 Expansion of the Capaciaty

The expansion decision variable indicates the maximal expansion within a year. The expansion of technology i is limited through the $\text{CapacityMax}_{i,t}$ variable in time t and has to be equal or greater than zero. It is assumed that the expansion cannot be negative, but can be zero in case of no additional capacity requirements. It just changes technology in case of cheaper variable costs during a period.

$$0 \leq e_{i,t} \leq \text{CapacityMax}_{i,t} \quad \forall i, \forall t$$

6.1.6 Technical Constraints

The technical constraints consist out of the implementation of the ramp up time, which only influences fuel fired power stations and nuclear power plants in the model. The ramp up time is the time difference between start of the generation units and its full utilization. The following equation describes modifications in the power production by the change in between consecutive hours.

$$|p(t, s, h, i) - p(t, s, h - 1, i)| \leq \delta C_{i,t} \quad \forall i, \forall t, \forall h \geq 2$$

Where the left term is absolute, in order to generate only positive values. The first part of the left equation indicates the production, whereby the index of h starts in the second hour. The second part of the left term describes the production in year t within the period s , but within the hours $h - 1$ for all technologies i . In other words, the production of the first term influences the production of the second term in the time of one hour. The right term of the equation above is the multiplication of the ramp up time δ that limits the possible capacity by a certain factor assumed (visible in Table 15: Power Plants Related Data) and the capacity variable $C_{i,t}$. This small difference within the production variable enables the calculation of hourly changes in between the starting process and the full power generation.

$$|p(t, s, H, i) - p(t, s, 1, i)| \leq \delta C_{i,t} \quad \forall i, \forall t$$

The second technical constraint differs according to changes in the hourly index. H indicates the last hour of the hourly index, in this case it is stated as 168, while 1 describes the first value. The right term is the same as in the first technical constraint mentioned above. The subtraction must be equal or lower than $\delta C_{i,t}$ and influences the production of the relevant technologies according to capacity possibilities.

6.2 Calculation of the Linear Programming Model with IBM ILOG CPLEX Optimization Studio

To solve the Linear Programming problem a program based on Cplex calculation systems, provided by IBM is used. IBM ILOG CPLEX Optimization Studio is described as a “consolidation of the OPL integrated development environment and the CPLEX® and CP Optimizer solution engines in a single product”¹³⁷. The Optimization Studio enables through the input of a source code a way to build efficient optimization models. The integrated development workbench (environment to enter the source code) and the clear modelling language support the users’ modelling development¹³⁸. The Optimization Programming Language (OPL) allows the user to enter linear objective functions with all belonging linear constraints to calculate mathematical programs. Generally the modelling language is based on the idea to simplify the complexity of mathematical programming problems¹³⁹. To express programming problems in a computer-language, a syntax provided by IBM has to be used. This syntax contains several data types such as sets and arrays, and also the input of algebraic notations in a computer language equivalent. For example an expression $\sum_{i=1}^n a_i x_i$ is written in the OPL format: `sum {i in 1..n} a[i] * x [i]`.¹⁴⁰

Generally it can be said that a linear programming model is a way to solve combinatorial search problems efficiently. The solution of the above described problem is an allocation of values to certain variables, which have to fulfil the constraints and finally compute the optimum of the value of the objective function. Notable is the large number of variables and constraints that can be solved with linear programming.

6.2.1 The Entry of the Source Code

¹³⁷ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Introducing IBM ILOG CPLEX Optimization Studio V12.2](#) - Introduction

¹³⁸ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Introducing IBM ILOG CPLEX Optimization Studio V12.2](#) Introduction

¹³⁹ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Language overview](#) – Modelling Language

¹⁴⁰ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Language overview](#) – Modelling Language

6.2.1.1 Declaration of the Data

Data declaration gives the possibility to name data entries in the model. Several options are provided to reference the input data according to its value¹⁴¹. String, which is used to define the technologies, allows the input of character sequences¹⁴². “Int” (short for Integer) allows only natural number¹⁴³s – so called positive integers $\in \mathbb{N}$, and is used for

- NbYears (the last year of the time horizon 2050)
- Initial Year 2008
- NbPeriods (the number of periods used – in total 4)
- NbHours (the number of hours of a week – in total 168)

Float is used for real numbers $\in \mathbb{R}$ ¹⁴⁴(e.g. the Discount Rate, which is stated with 7.5%) and Range is used to define a difference between two values¹⁴⁵. Tuple, which is used below, enables the declaration of data within an ordered pattern. The amount of values implied in a tuple is for all elements the same.

```
/* *****  
 * OPL 12.2 Model  
 * Author: Wüster Bernhard  
 * Creation Date: 14.06.2011 at 10:25:52  
 * *****/  
{string} Technology =...;  
  
int NbYears = ...;  
int InitialYear = 2008;  
range Years = 2009..NbYears;  
range Years2 = 2010..NbYears;  
int NbPeriods =...;  
range Periods = 1..NbPeriods;  
int NbHours =...;  
range Hours =1..NbHours;  
float DiscountRate = ...;  
range Years3 = 1980..NbYears;  
range Years4 = 1980..InitialYear;
```

¹⁴¹ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Understanding OPL projects](#) – Declarations of data

¹⁴² IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Basic data types](#) - Strings

¹⁴³ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Basic data types](#) – Integers

¹⁴⁴ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Basic data types](#) – Float

¹⁴⁵ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Data structures](#) - Tuples

```

tuple Datatype {
    int Lifetime;
    int InstallationTime;
    float RampUp;
}

```

Further the above mentioned declarations are used to define arrays. An array creates a data structure which is combined with given data, such as described in chapter 5.3.11, and indexed according to the data declaration¹⁴⁶ (See source code below). The external data such as Fixed Costs, Variable Costs etc. are brought in and indexed according to its affiliation.

```

int NumberOfPeriods[Periods]=[8, 15, 15, 14];
float FixedCosts[Technology][Years]=...;
float VariableCosts [Technology][Years]=...;
float Efficiency [Technology][Years]=...;
float Demand [Years][Periods][Hours]=...;
float CapacityMax [Technology][Years]=...;
float WindProd [Years][Periods][Hours]=...;
float WindProdOff [Years][Periods][Hours]=...;
float HydroProd [Years][Periods][Hours]=...;
float PVProd [Years][Periods][Hours]=...;
float DiscountFactor[Years];
float CapOld[Technology][Years4] =...;
int Lifetime[Technology]=...;
Datatype DataTech[Technology] =...;

```

Decision variables are the unknown figures in a linear programming model and differ from conventional variables in that they have “domains of possible values and may have constraints placed on the allowed combinations of these values”¹⁴⁷.

```

dvar float+ e[Technology][Years3];
dvar float+ p[Years][Periods][Hours][Technology];
dvar float+ c[Technology][Years];
dvar float+ Costs[Years];

execute Initizialize_DiscountFator {
    DiscountFactor[2009] = 1.0;
    for(var y in Years2)
        DiscountFactor[y] = DiscountFactor[y-1]*(1.0-DiscountRate);
}

```

The objective function describes the aim of the linear programming model which concludes in a maximization or minimization model. The objective function

¹⁴⁶ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Data structures](#) - Tuples

¹⁴⁷ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Understanding OPL projects](#) – Declaration of Decision Variables

contains only data declared or pre-calculated such as the “Discount-Factor” in the model. Introduced is the objective function whether by the keyword “minimize” or maximize¹⁴⁸.

```
minimize
    sum (t in Years, y in Years2) (DiscountFactor[y]*Costs[t]);
```

The indications to solve a linear programming problem are stated by the constraints and necessary to find a feasible solution. “Constraints are limits on the combinations of values for decision variables”¹⁴⁹. The implication of the decision variables into the constraints defines the optimization process. Constraints are declared within a “subject to” construction¹⁵⁰.

```
subject to {
    forall (t in Years)
        ctCosts:
        Costs[t]>= sum (s in Periods, h in Hours, i in
        Technology) (NumberOfPeriods[s] *
        VariableCosts[i][t]/Efficiency[i][t] * p[t][s][h][i])
        + sum (i in Technology) (e[i][t] * FixedCosts[i][t]);

    forall (t in Years, s in Periods, h in Hours)
        ctDemand:
        sum (i in Technology) p[t][s][h][i] == Demand[t][s][h];

    forall (i in Technology, t in Years, s in Periods,
    h in Hours)
        ctCapacity:
        0 <= p[t][s][h][i];

    forall (i in Technology, t in Years, s in Periods, h in Hours)
        ctCapacity2:
        p[t][s][h][i]<=c[i][t];

    forall (i in Technology, t in Years)
        ctCapacity3:
        c[i][t]<=CapacityMax[i][t];

    forall(k in Years4, i in Technology)
        ctpastCapBuild:
        e[i][k] == CapOld[i][k];

    forall (i in Technology, t in Years)
        ctCapacitynew:
```

¹⁴⁸ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Understanding OPL projects](#) – An Objective Function

¹⁴⁹ IBM ILOG CPLEX Optimization Studio V12.2 documentation - [Model](#) - Constraints

¹⁵⁰ ILOG CPLEX Optimization Studio V12.2 documentation - [Using constraints](#) – Modelling

```

        c[i][t] == sum(j in 1980..t-DataTech[i].InstallationTime)
        e[i][j] - sum(j in 1980..t-DataTech[i].Lifetime) e[i][j];

forall (t in Years, s in Periods, h in Hours)
    ctSetWind:
        p[t][s][h]["Windpower Onshore"] <= WindProd[t][s][h] *
        c["Windpower Onshore"][t];

forall (t in Years, s in Periods, h in Hours)
    ctSetWind1:
        p[t][s][h]["Windpower Offshore"] <= WindProdOff[t][s][h] *
        c["Windpower Offshore"][t];

forall (t in Years, s in Periods, h in Hours)
    ctSetPV:
        p[t][s][h]["PV"] <= PVProd[t][s][h] * c["PV"][t];

forall (t in Years, s in Periods, h in Hours)
    ctSetHydro:
        p[t][s][h]["Hydropower"] <= HydroProd[t][s][h] *
        c["Hydropower"][t];

forall (i in Technology, t in Years)
    ctExpansion:
        0<=e[i][t];

forall (i in Technology, t in Years)
    ctExpansion2:
        e[i][t]<=CapacityMax[i][t];

forall (i in Technology, t in Years, h in 2..168, s in Periods)
    ctRamp1:
        abs(p[t][s][h][i]-p[t][s][h-1][i]) <= DataTech[i].RampUp *
        c[i][t];

forall (i in Technology, t in Years, h in 2..168, s in Periods)
    ctRamp2:
        abs(p[t][s][168][i]-p[t][s][1][i]) <= DataTech[i].RampUp *
        c[i][t];
}

```

7 RESULTS

7.1 Electricity Demand Results

In this section the results of the linear programming are analysed. As mentioned above the yearly demand is extended by the hourly consumption within a so called period. These periods resemble the consumption of each season and are therefore divided into January (for winter) April (for spring), July (for summer) and October (for autumn). The following graph shows the hourly consumption of each periods in 2009 split into week/month. On the y-axis the used MWh per hour is listed.

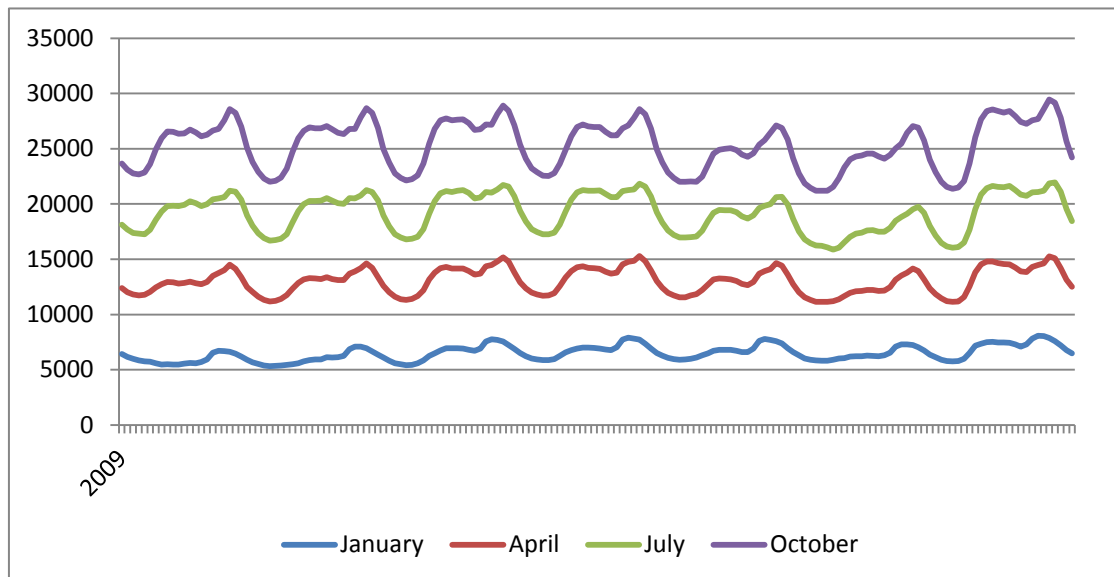


Figure 27: Hourly Demand per estimated Periods in 2009

To estimate the future consumption, the hourly demand is multiplied with a constant factor, visible in Table 16: Increase of the Constant Factor. The year 2008 was taken as a bench mark, and by the usage of the in section 3.2.1 described influencing rates, the increase of consumption is calculated. For a more simple overview only the realistic scenario is used, arguing that this is the initial situation calculated by the forecasting program.

Expanding the hourly demand data from 2008 with the data from the Table 16: Increase of the Constant Factor, above the consumption for several years are visible. To keep clarity only years range (2009 – 2015) are mapped. Visible in this graph is the slight increase of consumption over the years. Same as in Figure 27:

Hourly Demand per estimated Periods in 2009 the hourly demand of a period which reconstructs a season is taken.

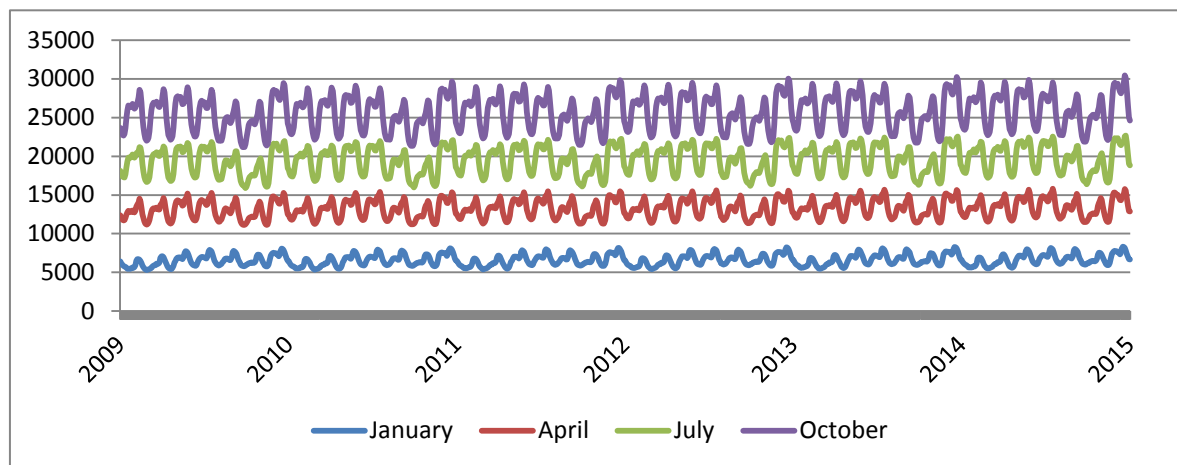


Figure 28: Hourly Demand per estimated Periods in 2009

7.2 Linear Programming Model Results

In this subsection, the outcome of the linear programming model for forecasts for the future electricity mix is reported. The outcome compares the changing capacity of three different price scenarios, whereby the data for the first scenario (“mäßig”) is shown in Table 12: Variable Costs / Technology (scenario 2 and 3 see Appendix). The results of the prediction are presented in graphs, considering the expansion and the overall capacity. The first scenario, which uses the “Variable Costs/Year “Mäßig” as a base, is used as a benchmark to compare the performances of the other scenarios (“deutlich”, “niedrig”). The findings of the electricity generation are divided into two groups. For a better overview all renewable sources and all thermal sources (fossil and nuclear) are summarized.

7.2.1 Results of the First Scenario “Mäßig”

The expansion for the future electricity mix is shown in the following graph. The future electricity market is dependent on the realized electricity market (1980-2008) and cannot exceed the maximum of possible capacity within a year. The graph shows only the future expansion per year. in order to give an overview the first graph shows the aggregation of thermal and renewable sources within the time horizon. Since the expansion differentiates for all technologies, further graphs are shown in the appendix section.

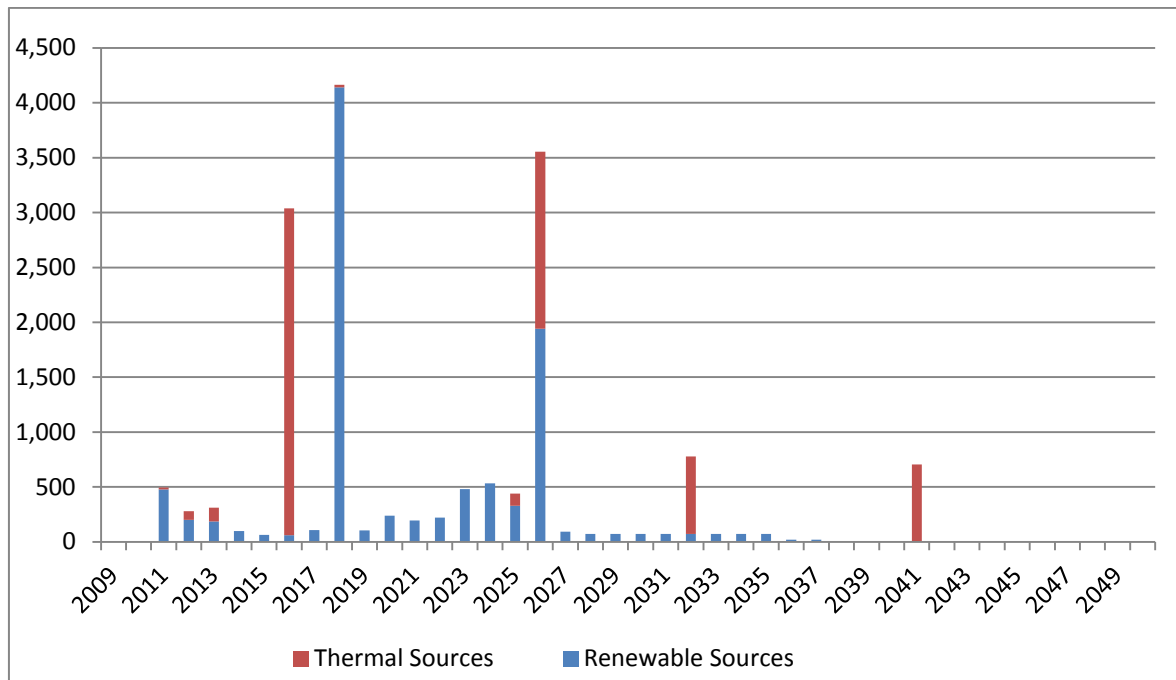


Figure 29: Expansion "Mäßig"

In this graph it is visible that the thermal expansion is strong in the year 2016, while in the year 2018 the expansion is characterized by the increase of renewable sources. In the year 2026 the expansion is both, thermal as well as renewable. Data rows, as well as the technology wise expansion are shown in the appendix.

The capacity corresponds to the demand and expansion according to life time and installation time of power stations. It increases/decreases due to demand requirements and decreases after expiration of the runtime. In the following graph the total capacity and further the differentiation between thermal and renewable sources is shown.

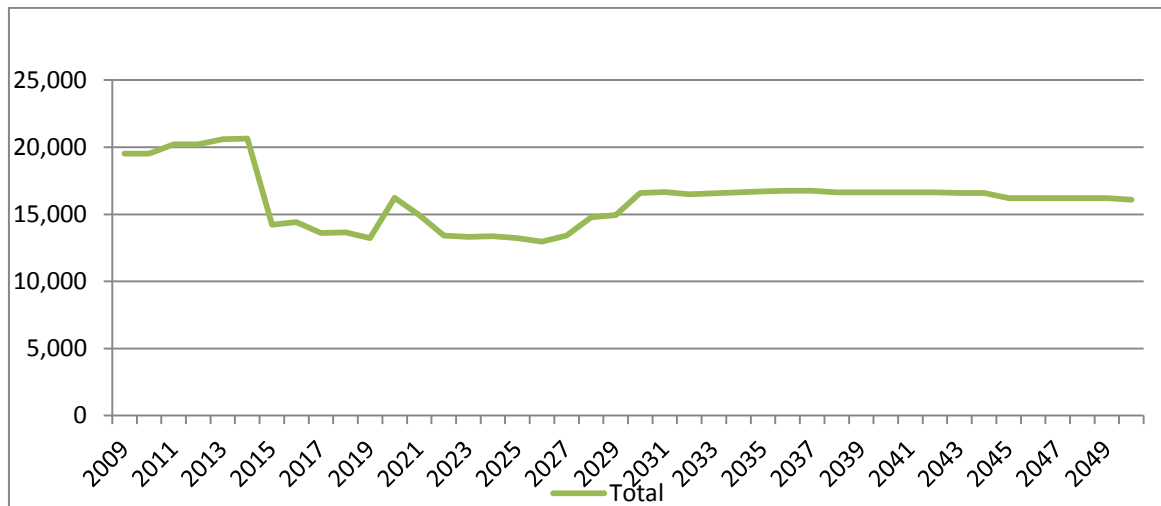


Figure 30: Total Capacity "Mäßig"

The total capacity starts in 2009 at 19.5 GWh increasing slightly to a maximum of 20.6 GWh in 2014 before a sharp decrease ends in 2015 at 14.2 GWh. The capacity reaches its temporary minimum in 2019 at 13.2 GWh before it increases up to 16.2 GWh 2020. After a decrease in 2021 (13.4 GWh) the capacity is growing to 16.6 GWh in 2030 before declining slightly to 16.1 GWh in 2050. To understand the movements of this graph a more detailed view is necessary.

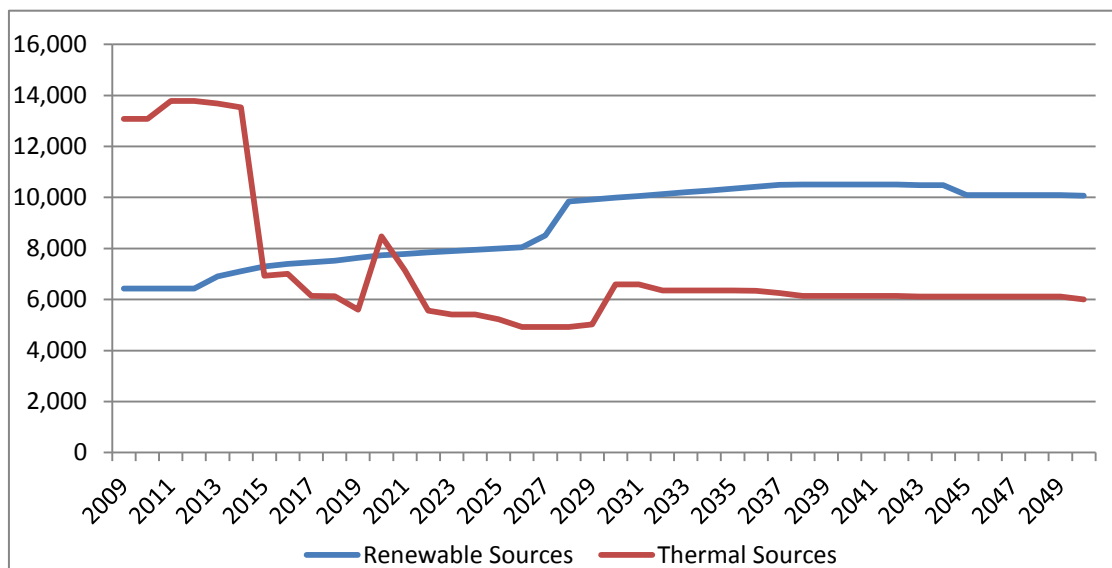


Figure 31: Capacity Renewable/Thermal Sources "Mäßig"

The sharp decrease of 2014 is caused by the end of runtimes of thermal power stations. The incline to the small peak of thermal power stations in 2020 is explained due to new installed capacity. The renewable sources are responsible

for the increase within the years 2023 – 2031. Afterwards a general downward movement of both, renewable and thermal power plant is apparent.

Noticeable is the time gap between the expansion and the increase of capacity during the time horizon. This gap emerges due to the installation time stated in Table 15: Power Plants Related Data. Furthermore, the decrease of capacity in the last decade stands out. The objective function is construed according to the lowest costs for the installation of power stations. As the time horizon is limited, only a small amount of capacities will be built in the last decade, due to costs that will not be earned until the end of the planning horizon. Only little expansion in the last two decades arises because of to the so called finals effect. Therefore only the results within the time horizon 2009 – 2030 reflect the possible future capacity.

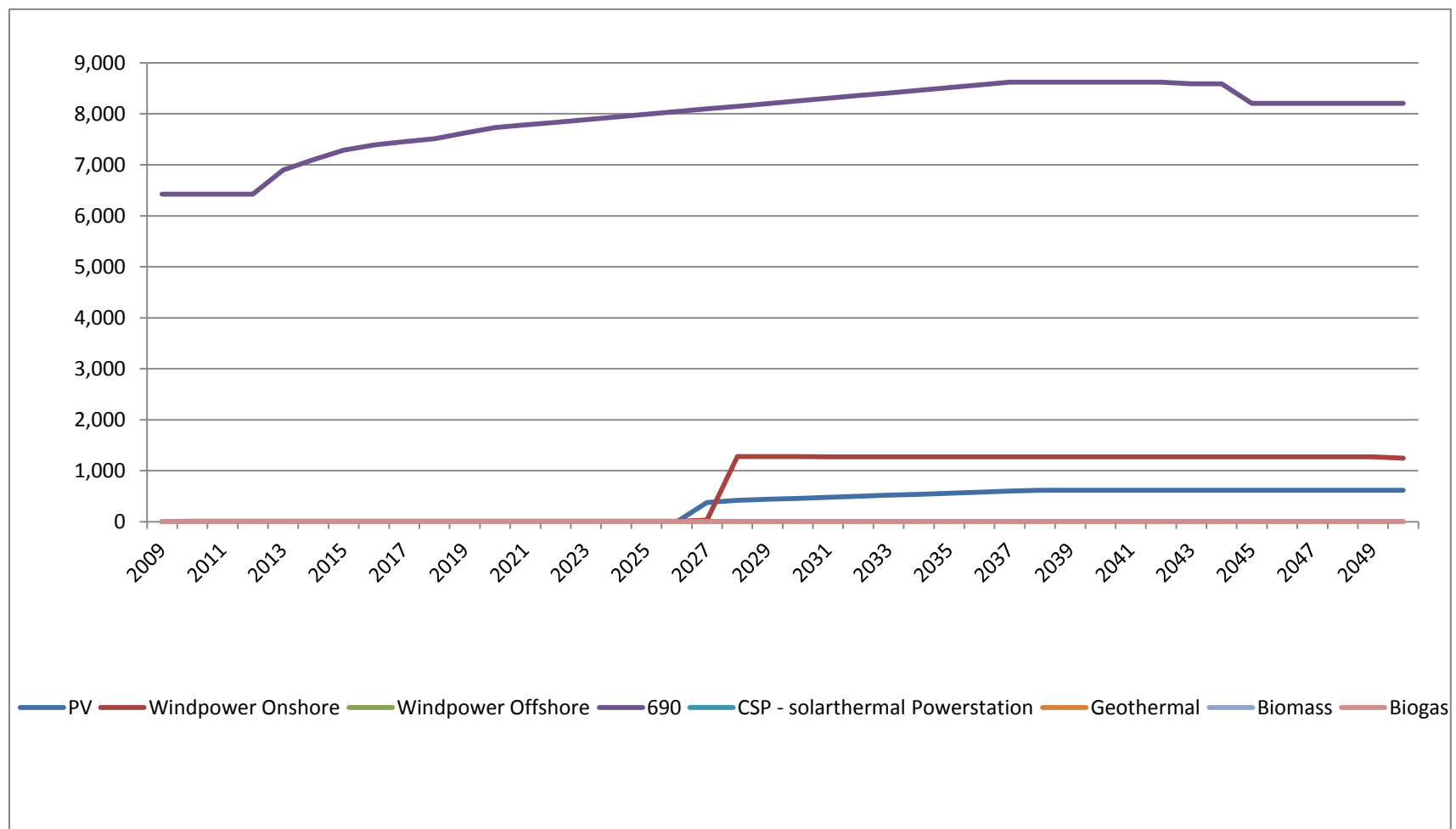


Figure 32: Capacity Renewable Sources "Mäßig"

The graph above shows the outcome for renewable source capacities over the planning horizon. The expansion for renewable sources will play an important role. Due to moderate price increases an excessive transformation to renewable sources is not apparent. Strong growth records hydropower, wind power onshore, while a smaller increase is visible for photovoltaic (PV). No expansion is given for the other renewable sources. Hydropower starts in 2009 with 6,400 MW staying constant until 2012 before it increases up to 6,900 MW installed capacity in 2013. From this point an upward trend until 2042, where it reaches 8,619.2 MW, followed by a slight decrease to the end of the time horizon where it finally has 8,203.2 MW.

The graph below deals with the capacity of thermal power stations. In the first years until 2014 the capacities of all power stations stay whether constant or increase. The only exception is natural gas, which declines not only due to the increase of variable costs, but also due to the end of approximated lifetime of existing power stations to a temporary minimum of 150 MW installed capacity. In 2015 a general decrease is clearly visible. The installed capacity in 2014 for lignite was 8,923.5 MW, for hard coal it was 1,585 MW, for crude oil it was 1,466 MW, while it decreased in 2015 to 4,802.5 MW for lignite, to 235 MW for hard coal and to 315 MW for crude oil. Also noticeable is extension for nuclear power, which is the only thermal power that stays after its increase in 2011 from 706 MW to 1412 MW constant over the planning horizon. The sharp decrease can be explained with the end of life times and the increase of variable costs for fossil fuel and certificates. In the graph below two further events are interesting in the capacity planning. On the one hand the sharp lignite capacity expansion rising from 3,580.5 MW in 2019 to a momentary maximum of 6,141.3 MW in 2020., Focusing only on the increasing demand lignite is the cheapest available source next to nuclear power. Thus nuclear power is limited to a maximum capacity of 1,412 MW, the expansion of lignite is necessary to meet demand requirements. On the other hand, the second interesting event is the extension of natural gas from 353.51 MW in 2029 to 1,967 MW in 2030. Although lignite is cheaper during that time, the linear program chooses according to lower specific costs, natural gas. This is expandable by the above mentioned final effect.

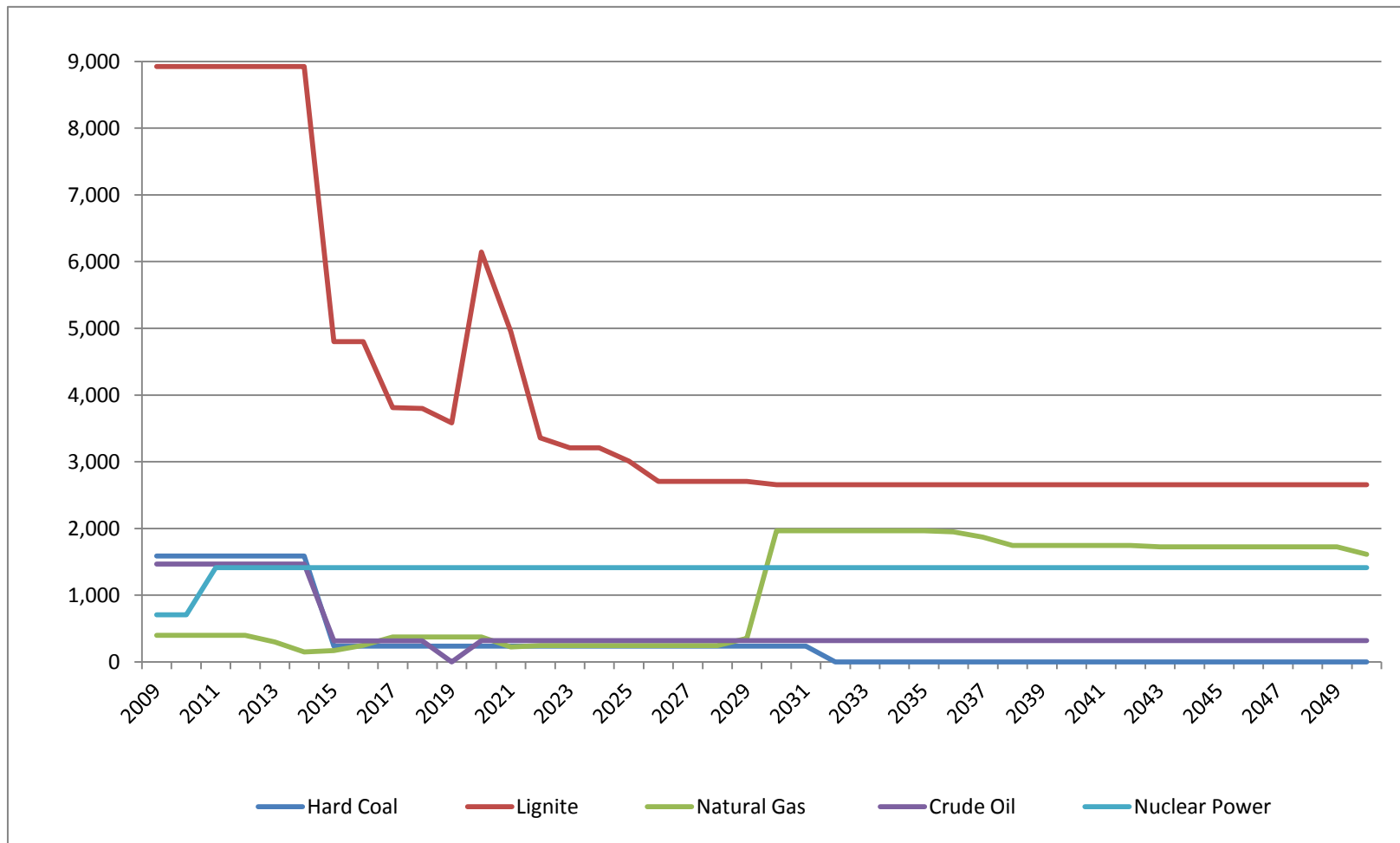


Figure 33: Capacity Thermal Sources "Mäßig"

7.2.2 Results of the Second Scenario “Niedrig”

The following graph shows the expansion of thermal and renewable power stations.

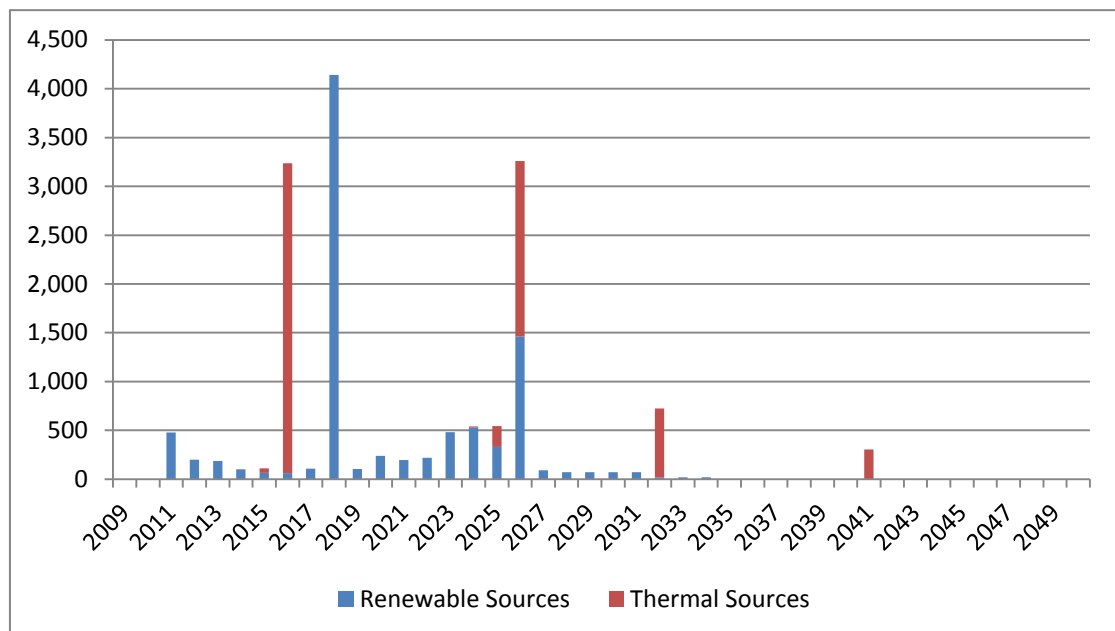


Figure 34: Expansion "Niedrig"

In contrast to the first scenario a sharp increase in 2016 for thermal power stations is noticeable, while a strong expansion for renewable power plants is apparent in 2018. The expansion for all forms of power stations is visible in the appendix. The differences for the different expansion are changes in price forecasts, also shown in the appendix. Important to mention is that the price forecast “Niedrig” for fossil fuel is set in comparison to the price forecast “Mäßig”, which is used as a benchmark, lower. On this account the greater expansion for thermal power is obvious.

Thus the total capacity is almost identical (until the year 2027) with the total capacity of the first scenario, a graph is not displayed. More interesting is the differences for thermal and renewable power. As already mentioned above, the distinction of the scenarios is caused by different fuel and CO₂ certificate price assumptions. The following graph presents the overall capacity for thermal and renewable power stations for the second scenario.

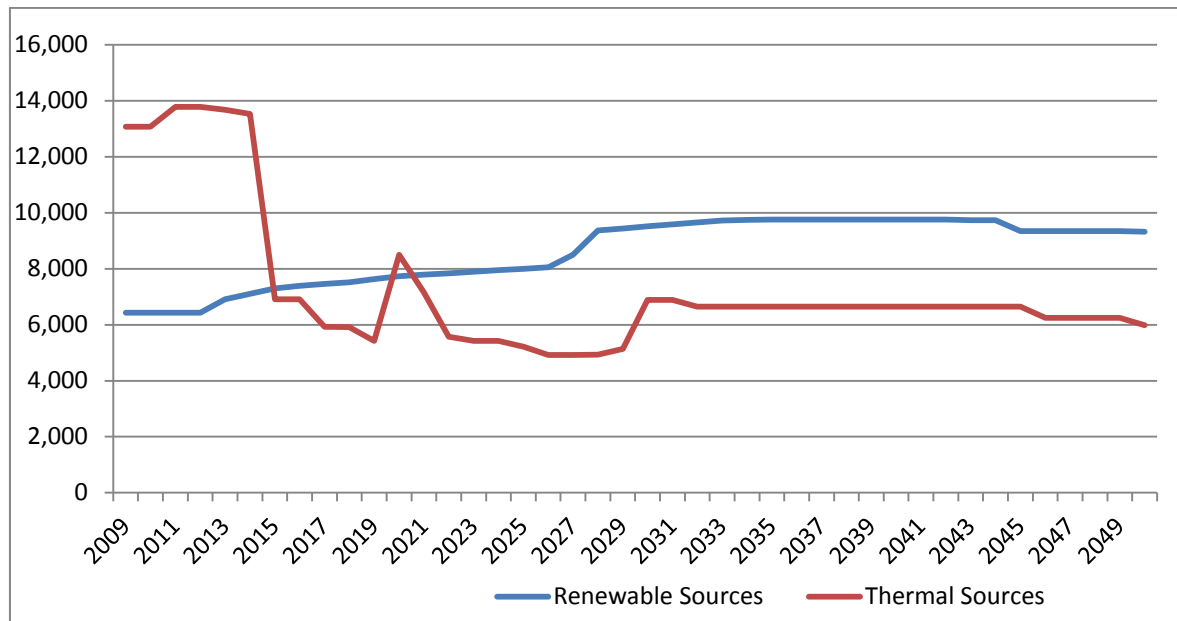


Figure 35: Capacity Renewable/Thermal Sources "Niedrig"

Noticeable is the layout of the lines, which looks similar to the first scenario. A clear differentiation to the first scenario does not exist, although a stronger expansion of thermal power station is identifiable. The reason for this similarity is caused by a similar increase of fuel prices.

The graph below describes the renewable sources capacity development for the second scenario. The capacity increase for hydropower is identical (until 2030) with the increase for hydro power in the first scenario. After 2030 a lower growth than in the first scenario is recognizable. The strong renewable expansion in 2018 is only ascribed to the extension of hydro power plants, while the expansion in 2026 affects the capacities for photovoltaic (PV), which increases in 2027 380 MW. PV is further growing until 2035 where it remains constant with 560 MW. Windpower Onshore, which inclines in 2028 to 803 MW, having its maximum for three years before decreasing slightly to 773 MW in 2050. There is no increase for any other renewable source.

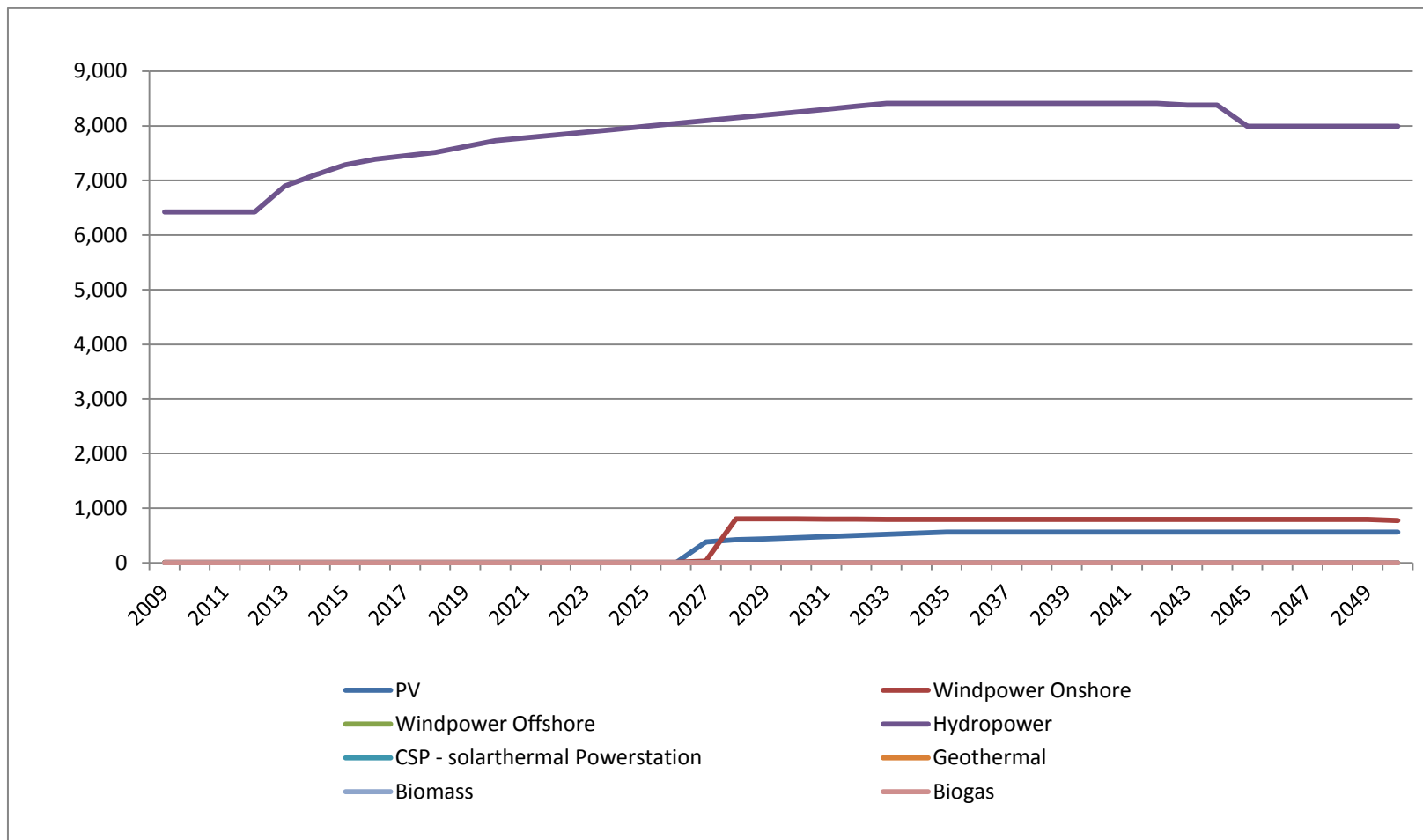


Figure 36: Capacity Renewable Sources "Niedrig"

The graph below shows the capacity expansion of thermal power stations in the scenario “Niedrig”. The layout of the lines of this graph is similar to the graph, regarding thermal power capacity from the first scenario. However, the capacity expansion for thermal power is growing to higher maximums as the in the first scenario. In the first five years (2014) most fossil fired power plants remain constant. According to life time changes for power plants the capacity of natural gas power plants are decreasing in 2012 from 400 MW to 300 MW in 2014. A further exception is nuclear power which increases its capacity in 2011 from 706 MW to 1,412 MW and stays constant until 2045 before decreasing to 1,011MW. Lignite reaches in 2015 4.802 MW followed by a further decline to a 3.580 MW in 2019. After this temporary minimum it increases in 2020 to 6,443 MW, before falling sharply in the period 2021-2022 to 3,659.7 MW. Hereafter a permanent downward movement is recognizable reaching 2,959.7 MW in 2030 remaining constant until 2050. Natural gas power plants increase due to the finals effect is capacity in 2030 to 2,017 MW, while crude oil fired power plants decrease its capacity in 2014 from 1,466 MW to 315 MW, due to high oil prices. Hard coal decreased in 2014 from 1.585 MW to 235 MW in 2015, where it remains constant until 2031. In 2032 no further capacity is need until 2050.

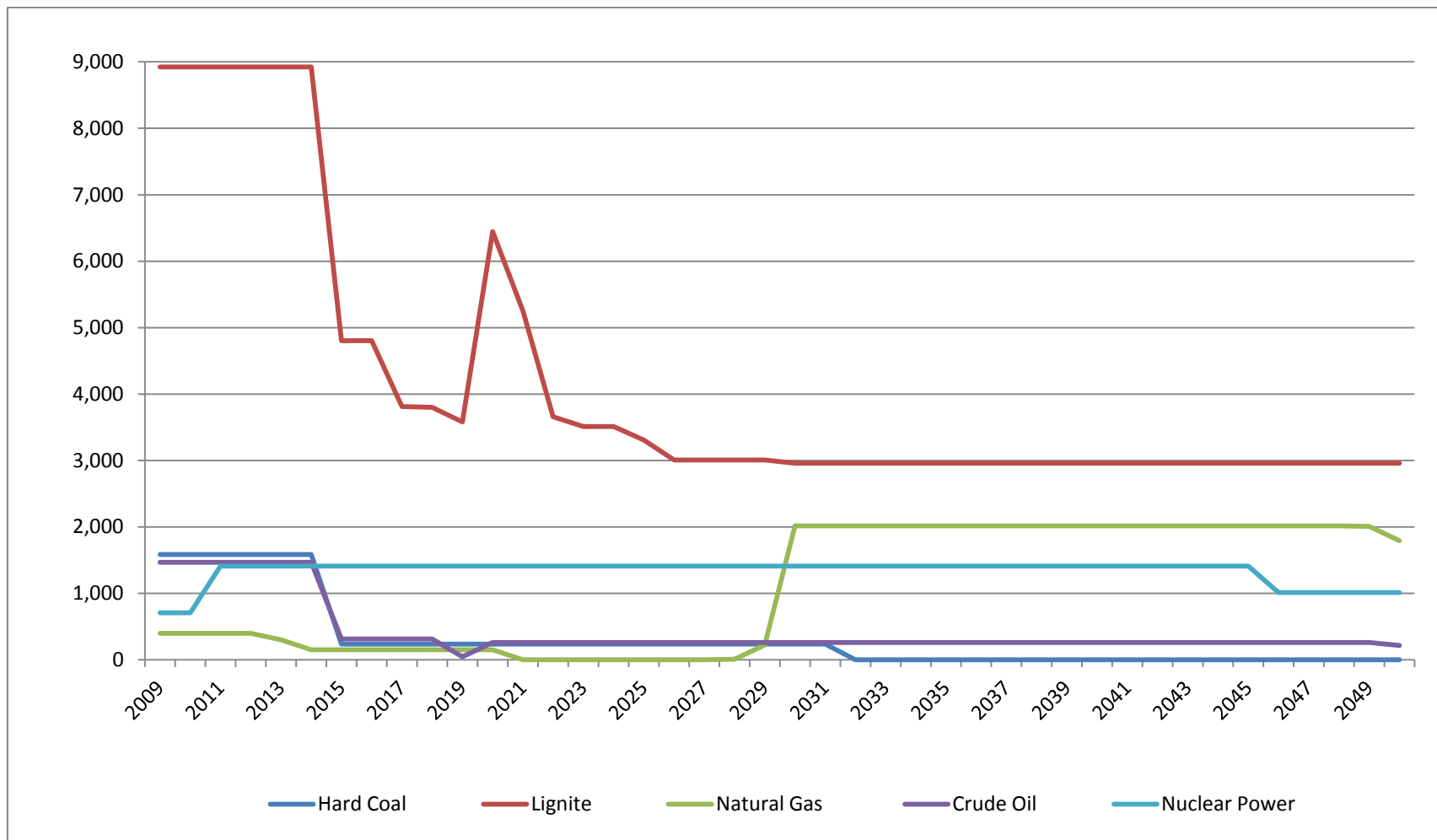


Figure 37: Capacity Thermal Sources "Niedrig"

7.2.3 Results of the Third Scenario “Deutlich”

In contrast to the second scenario, the price forecast above is the first scenario. In this scenario the prices differentiate completely to the first scenario, which is also visible in the graphs of this section. According to high fuel prices, and higher CO₂ certificate prices the expansion for renewable sources is obvious. In order to give an overview the following graph shows the expansion for thermal and renewable sources.

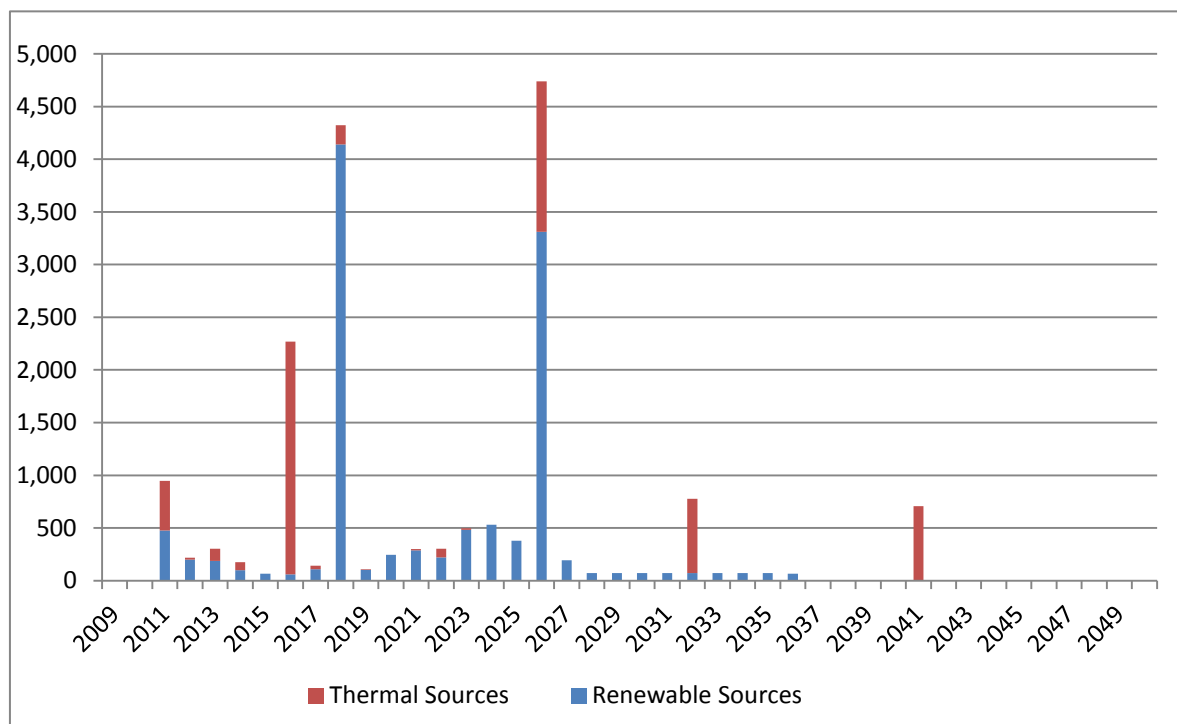


Figure 38: Expansion "Deutlich"

The strong expansion of renewable sources in the period 2017 – 2027 in the graph above stands out. The expansion, in comparison to the other scenarios, shifts from a thermal driven to a renewable sources driven expansion.

Changes in the total capacity structure are identifiable, but resemble more or less the total capacity structure of the two first periods. Same is in the first two scenarios the total capacity starts in 2009 at 19.5 GWh increasing to a maximum of 20.6 GWh in 2014 before it falls sharply to 14.7 GWh in 2015. The total capacity reaches its temporary minimum in 2019 at 13.2 GWh before it increases to 16.2 GWh in 2020. This short growth is followed by a sharp decrease in 2021 to 14.9 GWh continued by a slight downward trend until 2026 where it reaches its

absolute minimum of 12.9 GWh. A final increase leads the total capacity to 16.8 GWh in 2036 before it decreases slightly to 16 GWh in 2050.

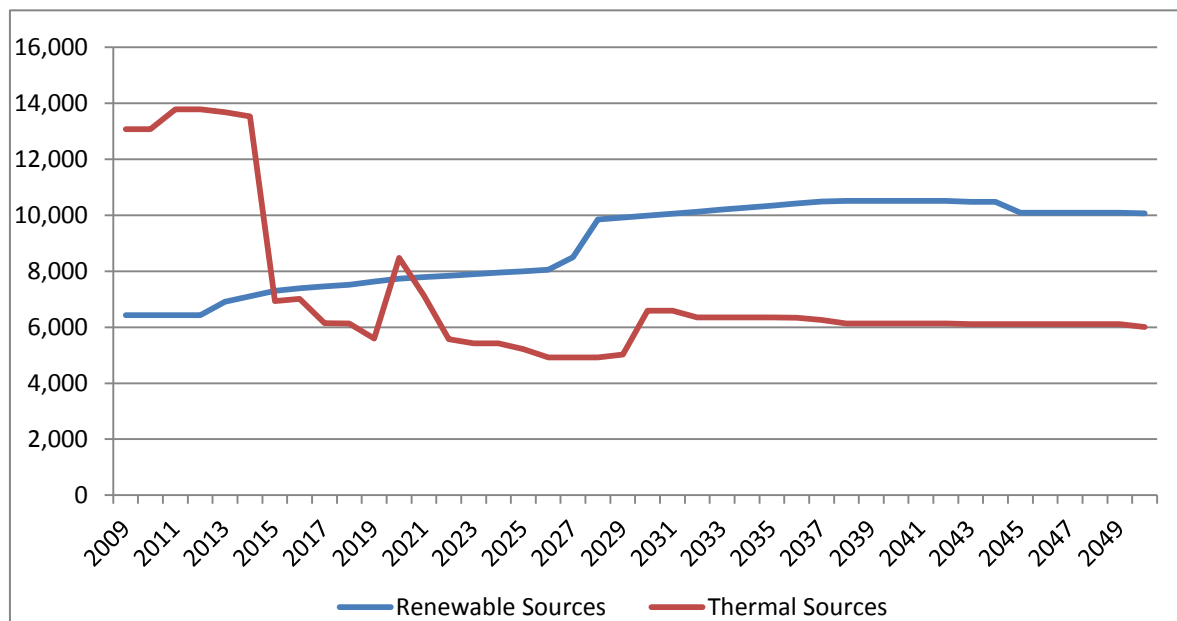


Figure 39: Capacity Renewable/Thermal Sources "Deutlich"

Similar to the other scenarios is the course of the lines in the graph. The difference however is the stronger expansion of renewable sources which is shown in the following graph, and the decrease of thermal sources capacity.

The graph below shows the capacity of renewable sources for the "Deutlich" price forecast. Clearly visible in this graph is the enhanced expansion of renewable sources. While in the other scenarios the main expansion was for hydropower, PV and windpower onshore, the renewable capacity expansion in this scenario is subjected to several sources such as hydropower, windpower onshore, PV, biomass and biogas. No consideration to a possible extension was given to windpower offshore, which is expandable due to high specific costs and low supply of wind within the planning period.

Similar to the other scenarios is the increase of hydropower over the years. A strong increase of windpower onshore is visible in 2028, where it reaches a capacity of 1,883.7 MW, while PV increases in 2027 to 400 MW growing up to 593.53 MW where it stays constant. Biomass and biogas heightens their capacity

in 2031, while biomass increase up to 720 MW and biogas reaches 174.74 MW, staying constant over the planning horizon.

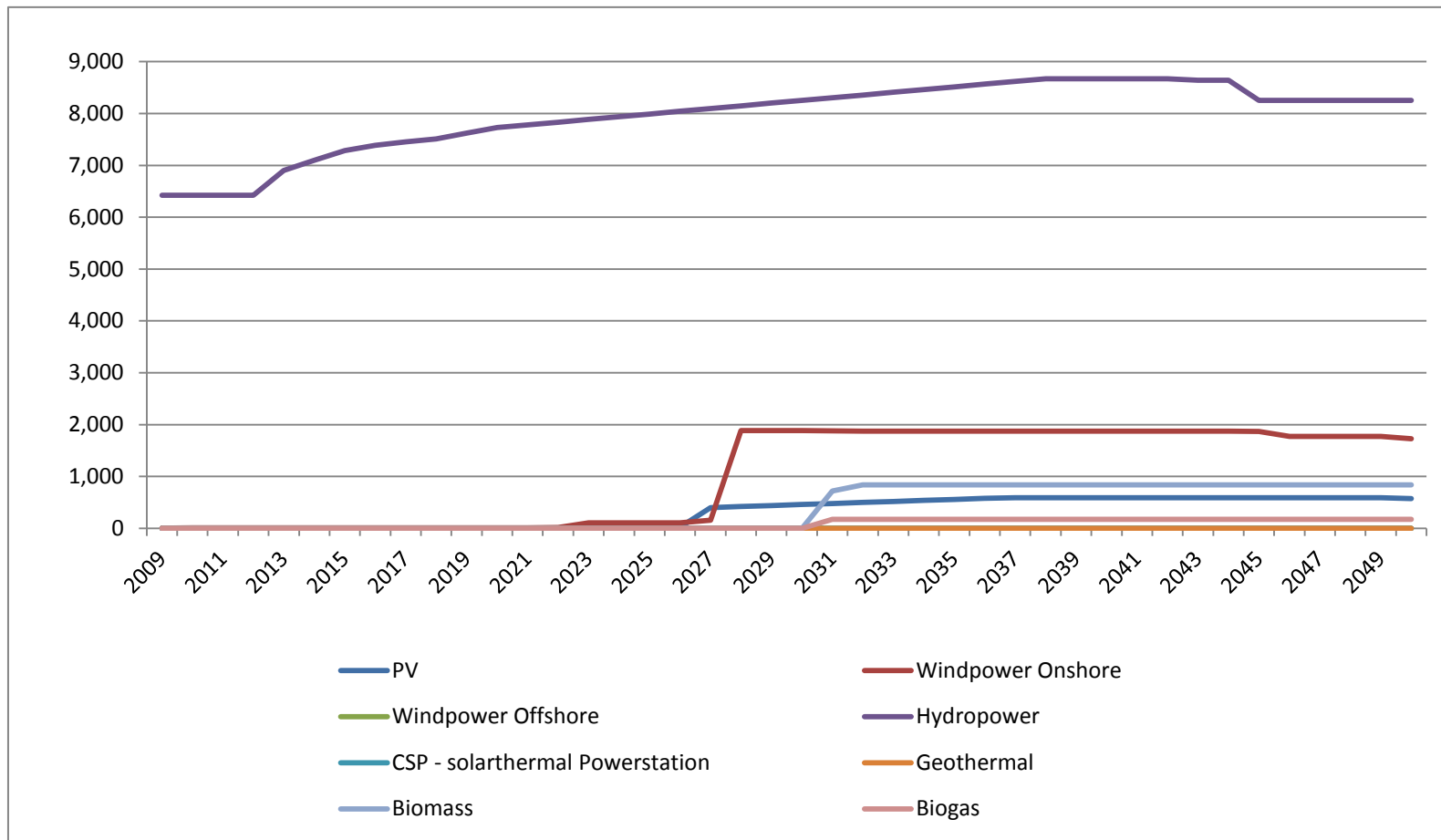


Figure 40: Capacity Renewable Sources "Deutsch"

A clear difference to the other scenarios is also visible in the development of the thermal power capacity shown in the graph below. Generally it can be said, that the thermal power capacity is marked by a severe capacity decrease of almost all power station forms. The only exceptions forms nuclear power, which stays constant within the time frame 2011 – 2050 at 1,412 MW and the natural gas that inclines after 2015 from 150 MW up to 2,438.10 MW in 2030 where it reaches its maximum. Lignite decreases in 2014 from 8,923.50 MW to 4,802.50 MW in 2050. This is explainable due to lifetime ends of lignite power stations. An expansion of lignite is noticeable in 2020 where it increases to a temporary maximum of 5,269.40 MW before declining to its minimum of 1,758.40 MW in 2030 where it stays constant until the end of the planning horizon. Due to increasing fuel prices and lifetime ends, hard coal and crude oil are also decreasing in 2015. Hard coal starts at a capacity of 1,585 MW in 2009 decreasing to 235 MW, where it remains constant until 2030, before declining to 0 MW over the rest of the planning horizon. The Crude oil capacity descends from 1,466 MW in 2009 to 315 MW in 2015. In 2019 crude oil reaches its temporary capacity minimum of 0 MW before growing up to 423.58 MW, remaining at the capacity until 2050. Same as in the other scenarios, the capacity forecast is valid only until to 2030 due to the finals effect described in section 7.2.1.

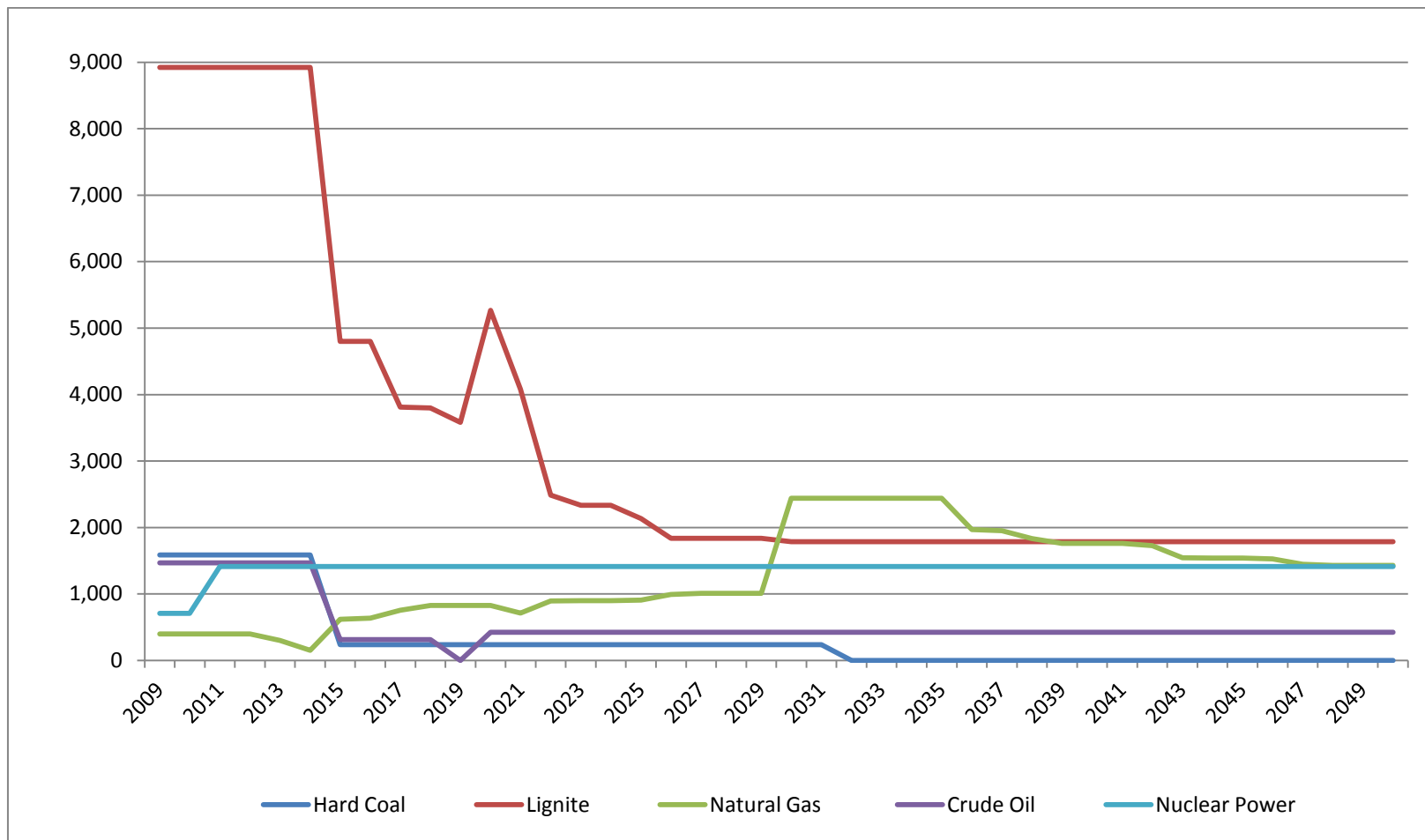


Figure 41: Capacity Thermal Sources "Deutsch"

8 CONCLUSION

Romania is one of Europe's growing markets, and its demand for energy must be satisfied. Although the consumption for primary energy decreased from 1990 until 2000 enormously, a noticeable growth for energy is clearly apparent. Growing energy demand goes hand in hand with the growth for electricity. To model the change in electricity consumption over years an electricity demand model was created.

Base for the calculation of the future electricity mix is, among other things, the electricity demand. The in this master thesis presented demand model forecasts the overall electricity consumption in Romania within in the time horizon 2008 – 2050. To calculate the long term electricity demand a similar model by Wei Hong was adopted. The division of sectors however corresponds to the classification of the IEA. To predict the future electricity consumption the demand model uses integrated rates to calculate the demand increase over time. The demand result complies more or less to a work, provided by SUSPLAN and increases up to 1.4 times of the current level.

To meet the future demand, new power stations must be built. Thus fuel prices and CO₂ certificate prices change over years the profitability for thermal power stations decrease. A general change of power generation forms has been discussed in the electricity market in the last years. Climate protection is and remains a significant topic in daily politics and challenges electricity providers and politicians equally. The type of future power plants as well as energy intensity keeps playing a major role. Especially in Europe climate topics defines the agenda of recent politics. The future energy mix, however is not only dependent on regulations and laws established by the European governments. A change is much more dependent on external influences such as fuel prices, CO₂ certificate prices and investment costs of all kinds of power stations.

Governmental regulations and laws are influences, which are difficult to calculate, because in terms of implementation of renewable power stations they devoid any

economical foundation. For this reason only external influences were taken into account, whereas the maximum capacity of thermal power will not be increased the today's status quo, while the future maximum capacity for renewables is overtaken from PNEAR. To model the new electricity production mix of Romania in the upcoming years a linear programming problem was formulated.

The future electricity mix bases on a linear programming model developed by the University of Vienna and the author. Several input factors, such as the specific power plant efficiency and utilization for renewable sources, fuel prices and CO₂ certificate prices, power plant life times, construction times, technical constraints as well as the electricity demand for the planning horizon were needed to calculate the hourly electricity production, the yearly capacity and the yearly extension by power plant over the planning horizon. The determination of the future electricity mix of Romania is dependent on the fuel prices and the CO₂ certificate prices over the planning horizon. To show the impact of changing price forecasts on the future electricity mix of Romania, three different scenarios, depending on fuel and CO₂ certificate price variations, were calculated.

The three different scenarios show the enormous impact of changing fuel and CO₂ certificate prices on the electricity mix and on the installed capacity respectively. Generally it can be said, that a higher price forecast leads to a higher investment in renewable sources, while lower fuel and CO₂ certificate prices reduce the commitment for investment in renewable sources – which finally results in the higher extension of thermal power plants. Interesting however is the change of MW in renewable/thermal sources, which depend on the price forecast. In the second scenario the installed capacity for renewable electricity is increasing very slowly while thermal power keeps on playing a major role. The third scenario is showing a completely different picture. The main power generation is done by renewable source, thermal power generation however is decreasing over time. The first scenario Mäßig is located in between the second and the third scenario, showing medium investments in renewable electricity sources. Thermal power generation however will play an important role in future electricity mix planning.

As a consequence the author notes that the electricity mix is, regardless of political influences and decisions, only driven by external factors, such as fuel and CO₂ prices as well as power plant efficiencies and utilization possibilities.

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10 APPENDIX

Fossil Fired Power Plants	Configuration	Fuel	Installation Year	Operation Year
ARAD	12	Natural Gas	1964	1964
ANINA	330	Brown Coal	1986	1986
	330	Brown Coal	1986	1986
	330	Brown Coal	1986	1986
BUZAU	6	Natural Gas	1967	1967
	6	Natural Gas	1967	1967
BUCURESTI SUD	50	Natural Gas	1965	1965
	50	Natural Gas	1968	1968
	100	Natural Gas	1975	1975
	100	Natural Gas	1975	1975
	125	Natural Gas	1975	1975
	125	Natural Gas	1975	1975
BUCURESTI VEST	125	Natural Gas	1975	1976
	125	Natural Gas	1975	1976
BACAU	50	Brown Coal	1988	1988
	50	Brown Coal	1988	1988
	50	Brown Coal	1988	1988
BOTOSANI	3	Brown Coal	1967	1967
BRAZI	50	Oil	1961	1963
	50	Oil	1961	1963
	50	Oil	1971	1973
	50	Oil	1971	1973
	50	Oil	1971	1973
	50	Oil	1971	1973
	150	Oil	1976	1976
	150	Oil	1976	1976
	200	Oil	1976	1976
	200	Oil	1976	1976
BRAZI II	50	Brown Coal	1979	1979
	50	Brown Coal	1979	1979
	50	Brown Coal	1986	1986
BLAJ	4	Brown Coal	1962	1962
Brasov	50	Brown Coal	1990	1990
	50	Brown Coal	1995	1995
BORZESTI	25	Natural Gas	1956	1960
	25	Natural Gas	1956	1960
	25	Natural Gas	1956	1960

	50	Natural Gas	1956	1960
	50	Natural Gas	1956	1960
	160	Natural Gas	1956	1960
	210	Natural Gas	1956	1960
	210	Natural Gas	1956	1960
BORZESTI II	50	Natural Gas	1975	1977
	50	Natural Gas	1975	1977
	50	Natural Gas	1975	1977
	50	Natural Gas	1982	1983
	50	Natural Gas	1982	1983
BRAILA	3	Natural Gas	1955	1955
	3	Natural Gas	1955	1955
	210	Brown Coal	1955	1955
	210	Brown Coal	1955	1955
	330	Brown Coal	1973	1974
	25	Brown Coal	1973	1974
	25	Brown Coal	1973	1974
	50	Brown Coal	1973	1974
BUCECEA	3	Brown Coal	1962	1962
	3	Brown Coal	1962	1962
BUCECEA	3	Brown Coal	1962	1962
	3	Brown Coal	1962	1962
CRAIOVA (Islanita)	55	Brown Coal	1964	1966
	50	Brown Coal	1964	1966
	50	Brown Coal	1964	1966
	50	Brown Coal	1964	1966
	100	Brown Coal	1967	1968
	100	Brown Coal	1967	1968
	315	Brown Coal	1967	1968
	315	Brown Coal	1967	1968
CRAIOVA II	50	Brown Coal	1964	1966
	50	Brown Coal	1964	1966
	50	Brown Coal	1964	1966
	100	Brown Coal	1964	1966
	100	Brown Coal	1964	1966
	100	Brown Coal	1964	1966
	315	Brown Coal	1967	1968
	315	Brown Coal	1967	1968
	55	Brown Coal	1967	1968
CORABIA	6	Brown Coal	1970	1970
	4	Brown Coal	1970	1970

CLUJ	30	Brown Coal	1970	1970
CALARASI	4	Brown Coal	1964	1964
	4	Brown Coal	1958	1958
CIMPINA	6.4	Brown Coal	1958	1958
COMANESTI	12	Brown Coal	1954	1954
	12	Brown Coal	1950	1950
CIMPULUNG MUSCEL	6	Brown Coal	1984	1984
	4	Brown Coal	1984	1984
DROBETA TR. SEVERIN	50	Brown Coal	1986	1991
	50	Brown Coal	1986	1991
	50	Brown Coal	1986	1991
	50	Brown Coal	1986	1991
	50	Brown Coal	1986	1991
	50	Brown Coal	1986	1991
DARMANESTI	4	Brown Coal	1956	1956
	5	Brown Coal	1956	1956
DANUBIANA	4	Brown Coal	1963	1967
	4	Brown Coal	1963	1967
	6	Brown Coal	1963	1967
DEJ	6	Brown Coal	1965	1966
	4	Brown Coal	1965	1966
	3	Brown Coal	1965	1966
	12	Brown Coal	1986	1987
	12	Brown Coal	1986	1987
Doicești	200	Brown Coal	1952	1955
	200	Brown Coal	1952	1955
	20	Natural Gas	1979	1982
	20	Natural Gas	1979	1982
	20	Natural Gas	1979	1982
	20	Natural Gas	1979	1982
	20	Natural Gas	1979	1982
	20	Natural Gas	1979	1982
DEVA	210	Hard Coal	1969	1971
	210	Hard Coal	1969	1971
	210	Hard Coal	1969	1971
	210	Hard Coal	1969	1971
	210	Hard Coal	1977	1980
	235	Hard Coal	1997	1997
FINTINELE	25	Natural Gas	1954	1958
	25	Natural Gas	1954	1958
	25	Natural Gas	1954	1958

	25	Natural Gas	1954	1958
	50	Natural Gas	1954	1958
	50	Natural Gas	1954	1958
FAGARAS	60	Brown Coal	1961	1961
GIURGIU	50	Brown Coal	1984	1986
	50	Brown Coal	1984	1986
	50	Brown Coal	1984	1986
Govora	50	Brown Coal	1960	1960
	50	Brown Coal	1969	1970
	50	Brown Coal	1975	1977
	50	Brown Coal	1975	1977
	50	Brown Coal	1986	1987
	50	Brown Coal	1986	1987
GROZAVESTI	25	Oil	1959	1964
	50	Oil	1959	1964
	50	Oil	1959	1964
GHERLA	3	Brown Coal	1962	1962
GRIVITA ROSIE	6	Brown Coal	1963	1963
GALATI	7	Oil	1968	1968
	7	Oil	1968	1968
	6	Oil	1968	1968
	6	Oil	1968	1968
	50	Oil	1983	1984
	100	Oil	1983	1984
	105	Oil	1983	1984
	60	Oil	1983	1984
GURA BARZA	7.3	Brown Coal	1954	1954
	19	Brown Coal	1954	1954
	19	Brown Coal	1954	1954
	34	Brown Coal	1954	1954
HUNEDOARA	6	Brown Coal	1964	1964
IASI	25	Natural Gas	1966	1972
	25	Natural Gas	1966	1972
	50	Natural Gas	1979	1979
	50	Natural Gas	1979	1979
IASI II	50	Natural Gas	1986	1988
	50	Natural Gas	1986	1988
LIVEZI (LUDUS IERNUT)	3	Natural Gas	1958	1963
	100	Natural Gas	1958	1963
	100	Natural Gas	1958	1963
	100	Natural Gas	1958	1963

	100	Natural Gas	1958	1963
	200	Natural Gas	1963	1964
	200	Natural Gas	1966	1966
LUDUS	3	Brown Coal	1962	1962
	3	Brown Coal	1962	1962
MILITARI	4	Brown Coal	1967	1967
NAVODARI	50	Brown Coal	1982	1984
	50	Brown Coal	1982	1984
	50	Brown Coal	1982	1984
	50	Brown Coal	1982	1984
ORADEA	25	Brown Coal	1960	1963
	25	Brown Coal	1960	1963
	50	Brown Coal	1960	1963
	50	Brown Coal	1960	1963
	50	Brown Coal	1960	1963
	100	Brown Coal	1960	1963
	100	Brown Coal	1960	1963
	100	Brown Coal	1960	1963
	100	Brown Coal	1960	1963
ORADEA II	50	Brown Coal	1987	1987
	50	Brown Coal	1987	1987
	50	Brown Coal	1987	1987
OVIDIU	12	Brown Coal	1952	1953
	12	Brown Coal	1952	1953
	12	Brown Coal	1952	1953
OCNA MURES	4	Brown Coal	1963	1963
PAROSENII	50	Hard Coal	1956	1959
	50	Hard Coal	1956	1959
	50	Hard Coal	1956	1959
	150	Hard Coal	1956	1959
PROGRESUL BUCURESTI	50	Natural Gas	1987	1989
	50	Natural Gas	1987	1989
	50	Natural Gas	1987	1989
PITESTI GAVANA	6	Natural Gas	1964	1964
	50	Natural Gas	1964	1964
	50	Natural Gas	1964	1964
PIPERA	3.5	Brown Coal	1964	1964
	1.5	Brown Coal	1964	1964
PITESTI	6	Brown Coal	1964	1964
PITESTI SUD	12	Brown Coal	1969	1970

	12	Brown Coal	1969	1970
	12	Brown Coal	1969	1970
	50	Brown Coal	1973	1975
	50	Brown Coal	1973	1975
PALAS	50	Natural Gas	1970	1971
	50	Natural Gas	1978	1978
	150	Natural Gas	1996	1996
PRUNDUL BIRGAULUI	2.5	Brown Coal	1985	1985
Rovinari	200	Brown Coal	1972	1972
	200	Brown Coal	1973	1973
	330	Brown Coal	1976	1976
	330	Brown Coal	1977	1977
	330	Brown Coal	1977	1977
	330	Brown Coal	1979	1979
RESITA	12	Brown Coal	1962	1964
RESITA	6	Brown Coal	1964	1964
RESITA 7 NOIEMBRIE	12	Brown Coal	1964	1964
ROZNOV	6	Brown Coal	1962	1963
	6	Brown Coal	1962	1963
SAVINESTI	6	Brown Coal	1970	1977
	12	Brown Coal	1970	1977
	12	Brown Coal	1970	1977
SIGHET	3	Brown Coal	1966	1966
SATU MARE	2.6	Brown Coal	1956	1956
SUCEAVA	50	Brown Coal	1987	1990
	50	Brown Coal	1987	1990
	50	Brown Coal	1987	1990
Turceni	330	Brown Coal	1978	1982
	330	Brown Coal	1978	1982
	330	Brown Coal	1978	1982
	330	Brown Coal	1984	1987
	330	Brown Coal	1984	1987
	330	Brown Coal	1984	1987
	330	Brown Coal	1984	1987
TIRNAVENI	21	Brown Coal	1961	1961
TIMISOARA	4	Brown Coal	1967	1967
	6	Brown Coal	1967	1967
	6	Brown Coal	1967	1967
	6	Brown Coal	1983	1983
	6	Brown Coal	1983	1983
TELEAJEN	6	Brown Coal	1956	1958

	6	Brown Coal	1956	1958
	6	Brown Coal	1956	1958
	12	Brown Coal	1980	1985
	12	Brown Coal	1980	1985
	12	Brown Coal	1980	1985
URZICENI	6	Brown Coal	1984	1985
	4	Brown Coal	1984	1985
VICTORIA	6	Brown Coal	1963	1963
	4	Brown Coal	1963	1963
	6	Brown Coal	1963	1963
VRANCEA ADJUD	6	Brown Coal	1984	1984
	4	Brown Coal	1984	1984
VULCAN	6	Brown Coal	1952	1952
ZALAU	12	Brown Coal	1984	1985
	12	Brown Coal	1984	1985
	12	Brown Coal	1984	1985
	12	Brown Coal	1984	1985

Table 17: Thermal Power Stations¹⁵¹¹⁵²¹⁵³

¹⁵¹ Instalatii Electrice Automatizare (2007 P.21 – 23)

¹⁵² IEA Clean Coal Centre (2004 P. 9)

¹⁵³ USAID (2007 P. D-9)

Hydropower Stations	Power/Turbine	Installation Year	Operation Year
SADU V	7.5	1955	1964
	7.5	1955	1965
	10	1955	1966
BICAZ	50	1960	1962
	50	1960	1963
	27.5	1960	1964
	27.5	1960	1965
	27.5	1960	1966
	27.5	1960	1967
ROZNOV II	7.5	1963	1964
	7.5	1963	1964
PINGARATI	11.5	1964	1964
	11.5	1964	1964
PIATRA MARE	5.5	1964	1964
	5.5	1964	1964
ZARNESTI	7.5	1964	1964
	7.5	1964	1964
COSTISA	7.5	1964	1964
	7.5	1964	1964
BUHUSI	5.5	1964	1964
	5.5	1964	1964
VADURI	22	1966	1966
	22	1966	1966
BACAU I	11.5	1966	1966
	11.6	1966	1966
BACAU II	7.5	1966	1966
	7.5	1966	1966
	7.5	1966	1966
	7.5	1966	1966
ARGES	215	1966	1966
	215	1966	1966
	215	1966	1966
	215	1966	1966
OIESTI	7.5	1967	1967
	7.5	1967	1967
ALBESTI	7.5	1967	1967
	7.5	1967	1967
STRIMTORI	4.2	1967	1967
CUMPANITA	4.6	1967	1967
CERBURENI	8.2	1968	1968

	8.2	1968	1968
PORTILE DE FIER	178	1970	1971
	178	1970	1971
	178	1970	1971
	178	1970	1971
	178	1970	1971
	178	1970	1971
PALTINU	5.5	1971	1971
	5.5	1971	1971
BASCOV	3.75	1971	1971
	3.75	1971	1971
CURTEA DE ARGES	3.75	1972	1972
	3.75	1972	1972
PITESTI	3.75	1972	1972
	3.75	1972	1972
LOTRU	174	1973	1975
	174	1973	1975
	174	1973	1975
NOAPTES	7.7	1973	1973
	7.7	1973	1973
ZIGONENI	7.7	1973	1973
	7.7	1973	1973
BAICULESTI	7.7	1974	1974
	7.7	1974	1974
RIMNICU VILCEA	23	1974	1975
	23	1974	1976
TARNITA	23.5	1974	1974
	23.5	1974	1974
MINICESTI	7.7	1975	1975
	7.7	1975	1975
GOVORA	23.5	1975	1975
	23.5	1975	1975
POIANA UZULUI	3.4	1976	1976
	0.7	1977	1977
VILCELE	7.75	1976	1976
	7.75	1976	1976
MERISANI	5.75	1976	1976
	5.75	1976	1976
DAIESTI	18.15	1976	1976
	18.15	1976	1976
LESU	3.4	1976	1976

RIURENI	24	1977	1977
	24	1977	1977
MARISELU	73.5	1977	1977
	73.5	1977	1977
	73.5	1977	1977
GILAU I.	4.8	1977	1984
	0.75	1977	1985
STINCA COSTESTI	7.5	1978	1978
	7.5	1978	1978
BUDEASA	5.75	1978	1978
	5.76	1978	1978
BABENI	18.5	1978	1978
	18.5	1978	1978
IONESTI	19	1978	1978
	19	1978	1978
MALAIA	9	1978	1978
	9	1978	1978
PUCIOASA	1	1979	1979
	1	1979	1979
ZAVIDENI	19	1979	1980
	19	1979	1981
STRAJESTI	25	1979	1979
	25	1979	1979
MOTRU	25	1979	1979
	25	1979	1979
HERCULANE	2	1979	1979
	5	1979	1979
	25	1979	1979
DRAGASANI	22.5	1980	1981
	22.5	1980	1982
ARGESTI	19	1980	1980
	19	1980	1980
GILCEAG	75	1980	1980
	75	1980	1980
BUCECEA	1.03	1981	1981
	0.07	1981	1981
BELCI	0.5	1981	1981
	0.5	1981	1981
CALIMANESTI	19	1981	1982
	0.35	1981	1983
SLATINA	13	1981	1981

	13	1981	1981
GURA RIULUI	3.5	1981	1981
	0.07	1981	1981
TURNU	35	1982	1982
	35	1982	1982
BRADISOR	57.5	1982	1982
	57.6	1982	1982
ASTILEU II	1.1	1982	1982
	1.1	1982	1982
SCROPOASA	6	1983	1984
	6	1983	1985
GOLESTI	4	1983	1983
	4	1983	1983
TISMANA	53	1983	1983
	53	1983	1983
SOMESUL CALD	12	1983	1983
CINCIS I	0.8	1983	1983
CINCIS II	0.8	1983	1983
PETRESTI	2	1983	1986
	2	1983	1986
GALBENI	14.5	1984	1984
	0.15	1984	1984
VLADESTI	0.7	1984	1986
	0.7	1984	1986
	0.8	1984	1986
	0.6	1984	1986
SUGAG	75	1984	1984
	75	1984	1984
BORZESTI	0.5	1984	1984
	0.5	1984	1984
OLANESTI	0.032	1984	1984
PORTILE.DE FIER II	27	1985	1986
	27	1985	1986
	27	1985	1986
	27	1985	1986
	27	1985	1986
	27	1985	1986
	27	1985	1986
	27	1985	1986
RACACIUNI	22.5	1985	1985
	22.6	1985	1985

	1.05	1985	1985
DIMBOVITA -CLABUCET	32	1985	1985
	32	1985	1985
TISMANA AVAL	1.5	1985	1985
	1.5	1985	1985
REMETI	50	1985	1985
	50	1985	1985
VOINEASA III	0.25	1985	1985
	0.25	1985	1985
BERESTI	21.75	1986	1986
	21.75	1986	1986
DRIDU	0.6	1986	1986
	0.6	1986	1986
	0.6	1986	1986
	0.6	1986	1986
	0.23	1986	1986
GURA LOTRULUI	12.4	1986	1987
	12.4	1986	1987
IPOTESTI	13.25	1986	1987
	13.25	1986	1987
	13.25	1986	1987
	13.25	1986	1987
OSTROVUL MIC	7.95	1986	1987
	0.08	1986	1987
GILAU II	5.4	1986	1987
	0.75	1986	1987
FLORESTI II	0.22	1986	1987
	0.22	1986	1987
	0.22	1986	1987
	0.22	1986	1987
	0.22	1986	1987
	0.22	1986	1987
VOINEASA I	0.22	1986	1986
	0.22	1986	1986
	0.22	1986	1986
VOINEASA II	0.22	1986	1986
	0.22	1986	1986
SEBES	0.4	1986	1986
	0.4	1986	1986
SURDUC	1	1986	1986
	1	1986	1986

DAICIVICIU	0.076	1986	1986
HOREZU II	0.5	1986	1986
	0.5	1986	1986
RIUL MARE RETEZAT	167.5	1986	1986
	167.5	1986	1986
AGIGEA	50	1987	1987
	50	1987	1987
LERESTI	19	1987	1987
VOINESTI	5.8	1987	1987
DRAGANESTI	13.25	1987	1987
	13.25	1987	1987
	13.25	1987	1987
	13.25	1987	1987
CLOCOTIS	10	1987	1987
SASCIORI	21	1987	1987
	21	1987	1987
CLOPOTIVA	7	1987	1987
	7	1987	1987
FLORESTI I	5.4	1987	1987
	5.4	1987	1987
	0.75	1987	1987
NEDELEA I	0.22	1987	1987
	0.22	1987	1987
	0.22	1987	1987
	0.22	1987	1987
ROGOJESTI	1.5	1988	1988
	0.6	1988	1988
NEHOIASU	21	1988	1988
	21	1988	1988
FRUNZARU	13.25	1988	1988
	13.25	1988	1988
	13.25	1988	1988
	13.25	1988	1988
OSTROVUL MARE	7.95	1988	1988
	7.95	1988	1988
CIRNESTI I	7.95	1988	1988
	7.95	1988	1988
CIRNESTI	7.95	1988	1988
	7.95	1988	1988
PACLISA	7.95	1988	1988
	7.95	1988	1988

	0.07	1988	1988
	0.07	1988	1988
TOTESTI I	7.95	1988	1988
	7.95	1988	1988
MUNTENI I	29	1988	1988
	29	1988	1988
COLIBITA	21	1988	1988
CLUJ	0.175	1988	1988
	0.175	1988	1988
	0.175	1988	1988
	0.175	1988	1988
	0.75	1988	1988
CIBIN	0.425	1988	1988
	0.425	1988	1988
	0.425	1988	1988
	0.425	1988	1988
Cornetu	15.5	2003	2003
	15.5	2003	2003
Others	384.662		

Table 18: Hydro Power Plants¹⁵⁴¹⁵⁵

Name	Power/Turbine	Installation Year	Operation Year
Cernavoda Nuclear Power Plant	706	1982	1997
	706	1983	2006

Table 19: Nuclear Power Stations¹⁵⁶

Operator	Total Installed Capacity	Installation Year	Status
Holrom srl	2.65	2008	Operational
Electrogrup srl	0.285	2007	Operational
Electric Prodsrl	0.6	2007	Operational
Green Energy Grup srl	2.25	2007	Operational
ILEXIMP	0.25	2007	Operational
BLUE LINE	0.285	2007	Operational
ELECTRO MARGO LINE	0.285	2007	Operational
Ecoprod srl	0.65	2007	Operational

Table 20: WindPower¹⁵⁷

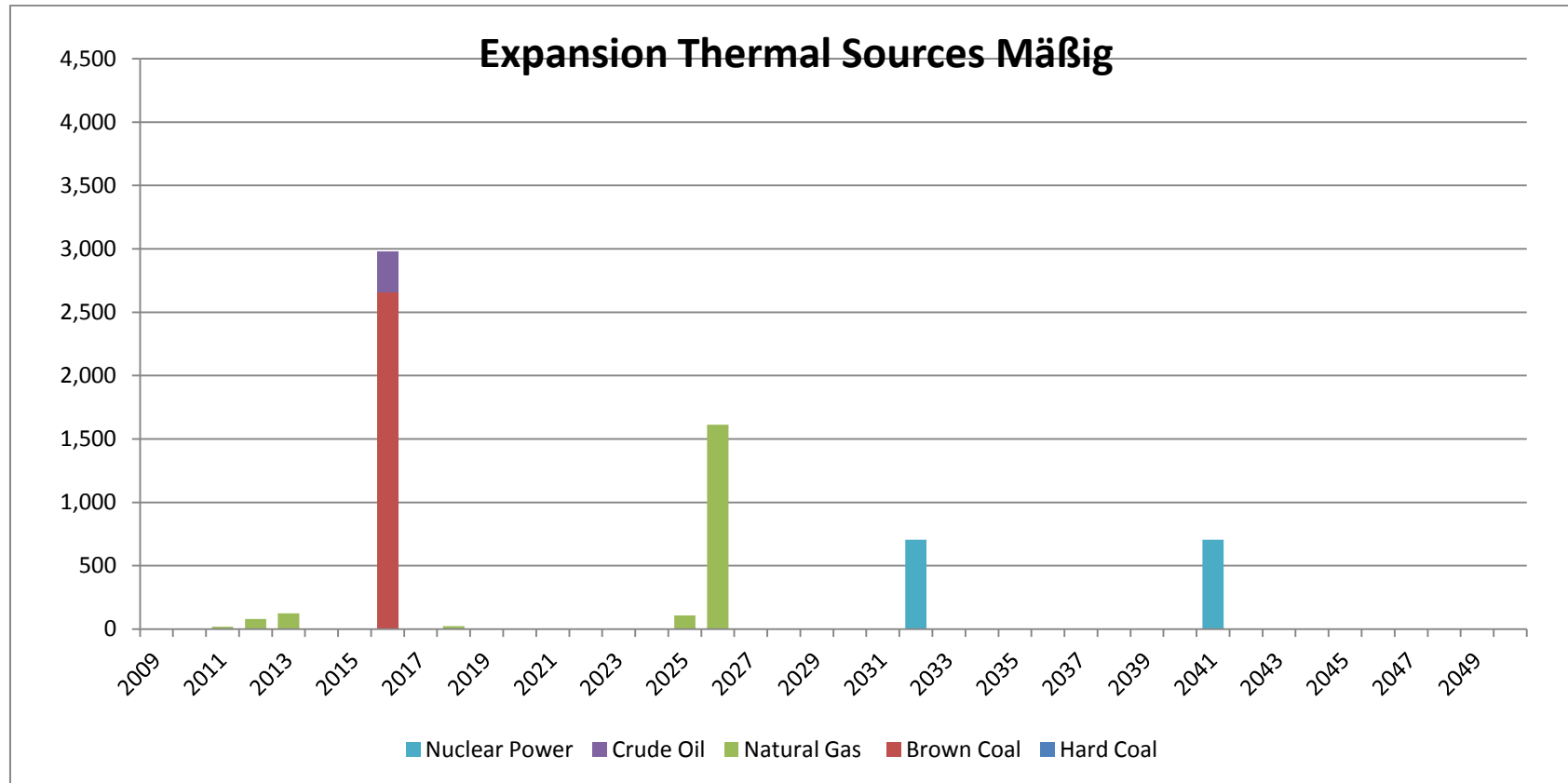
¹⁵⁴ Instalatii Electrice Automatizare (2007 P.23 – 26)

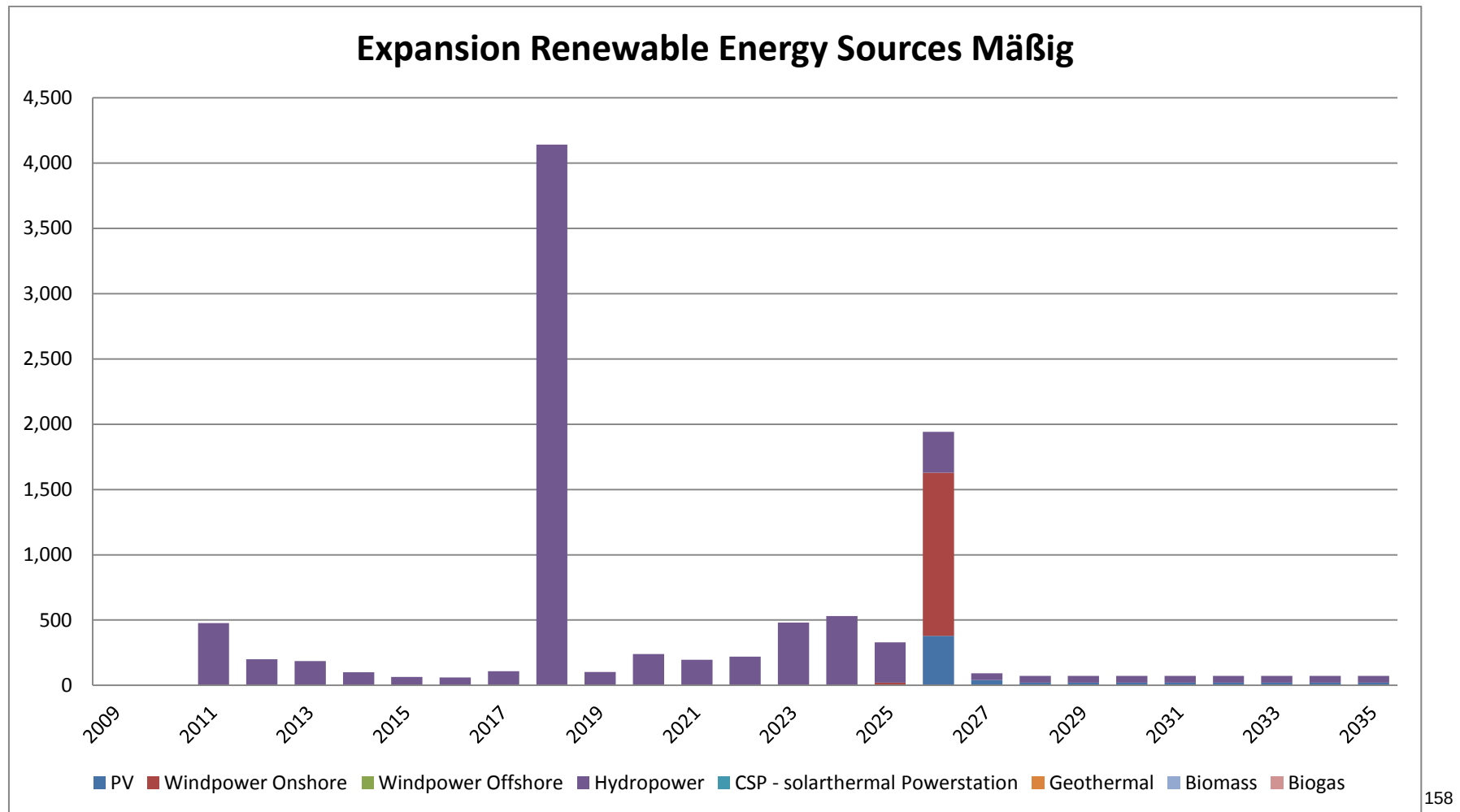
¹⁵⁵ IEA Clean Coal Centre (2004 P. 9)

¹⁵⁶ IEA Clean Coal Centre (2004 P. 10)

¹⁵⁷ www.thewindpower.net (2011)

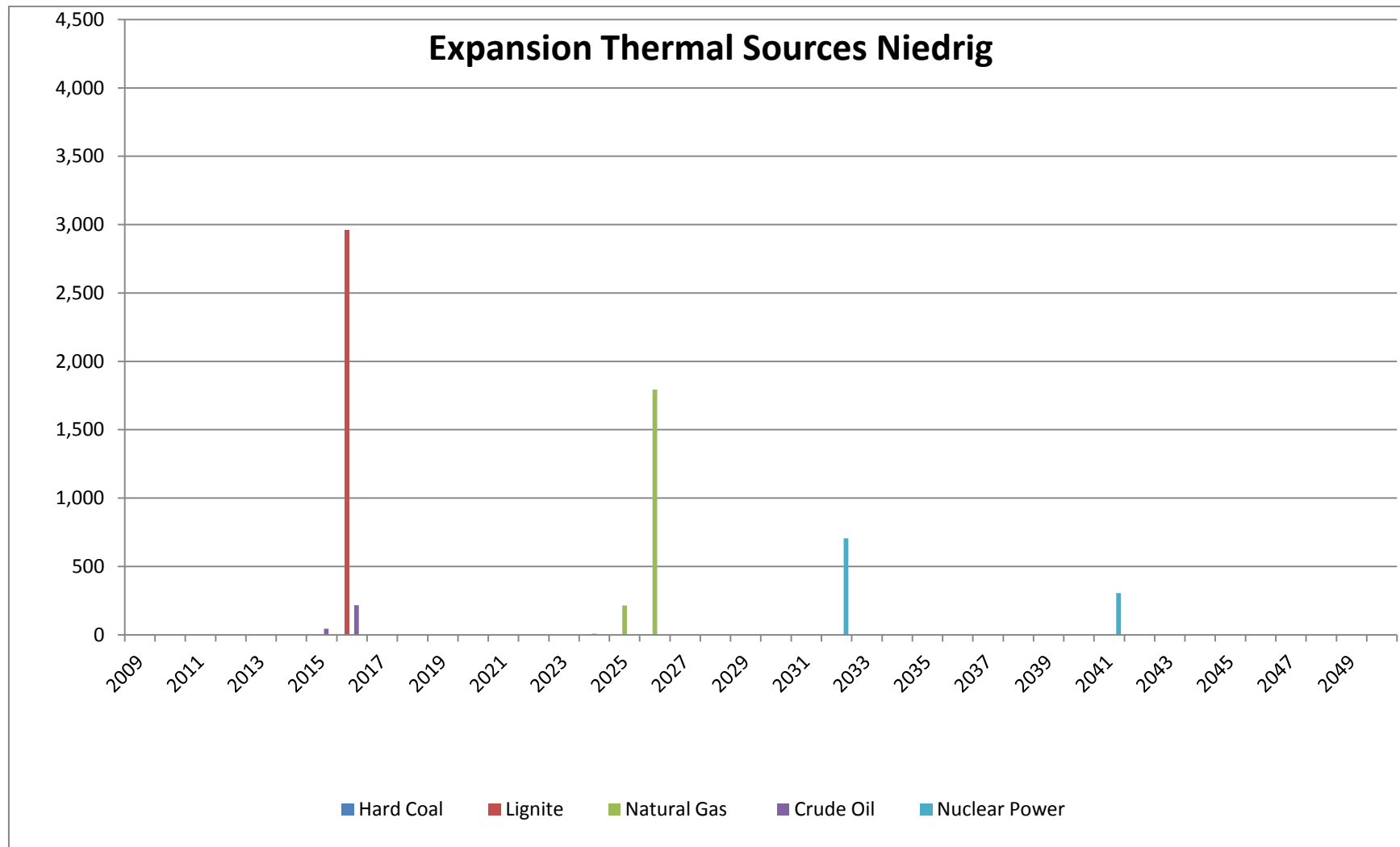
Expansion of all Scenarios

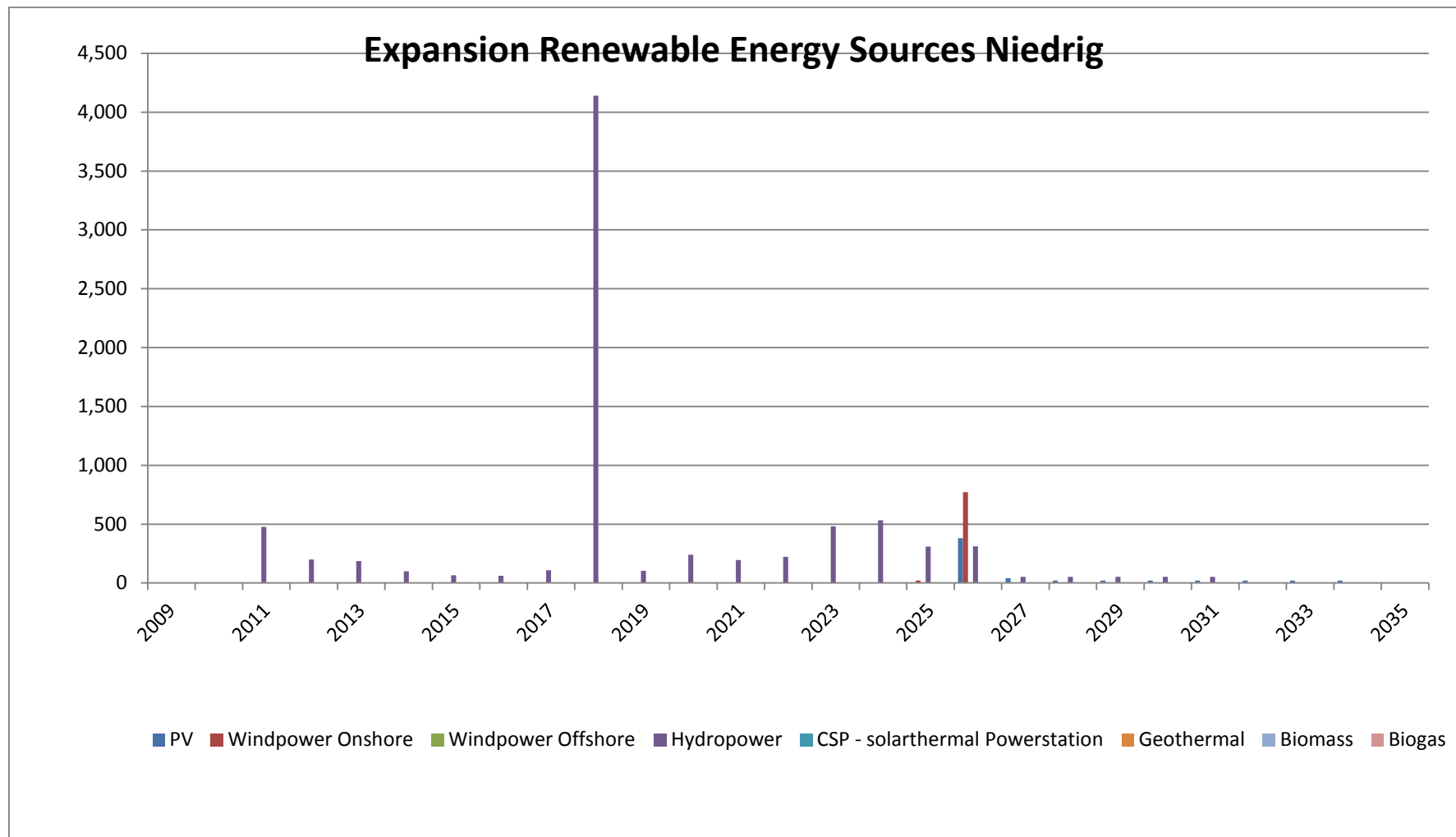


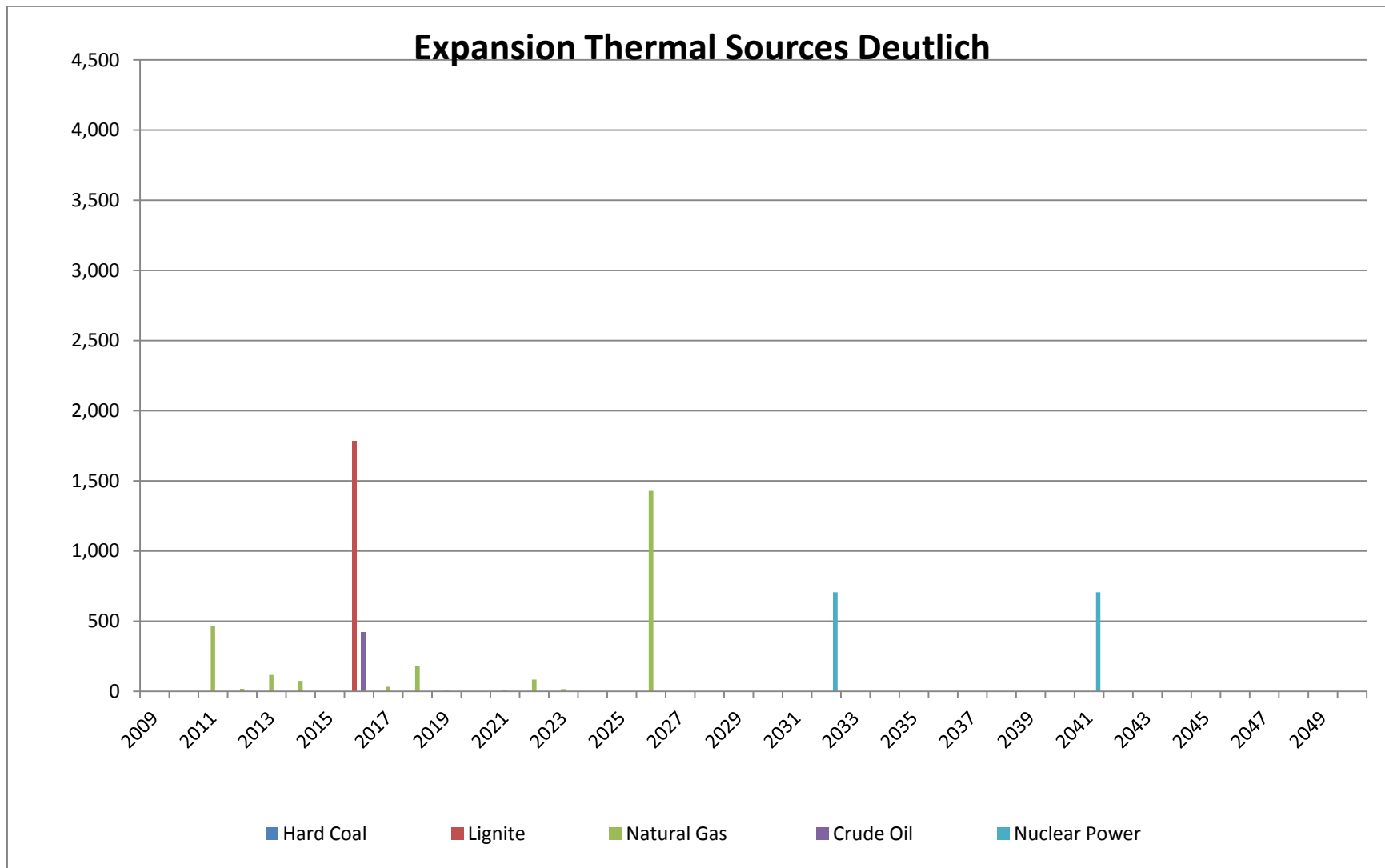


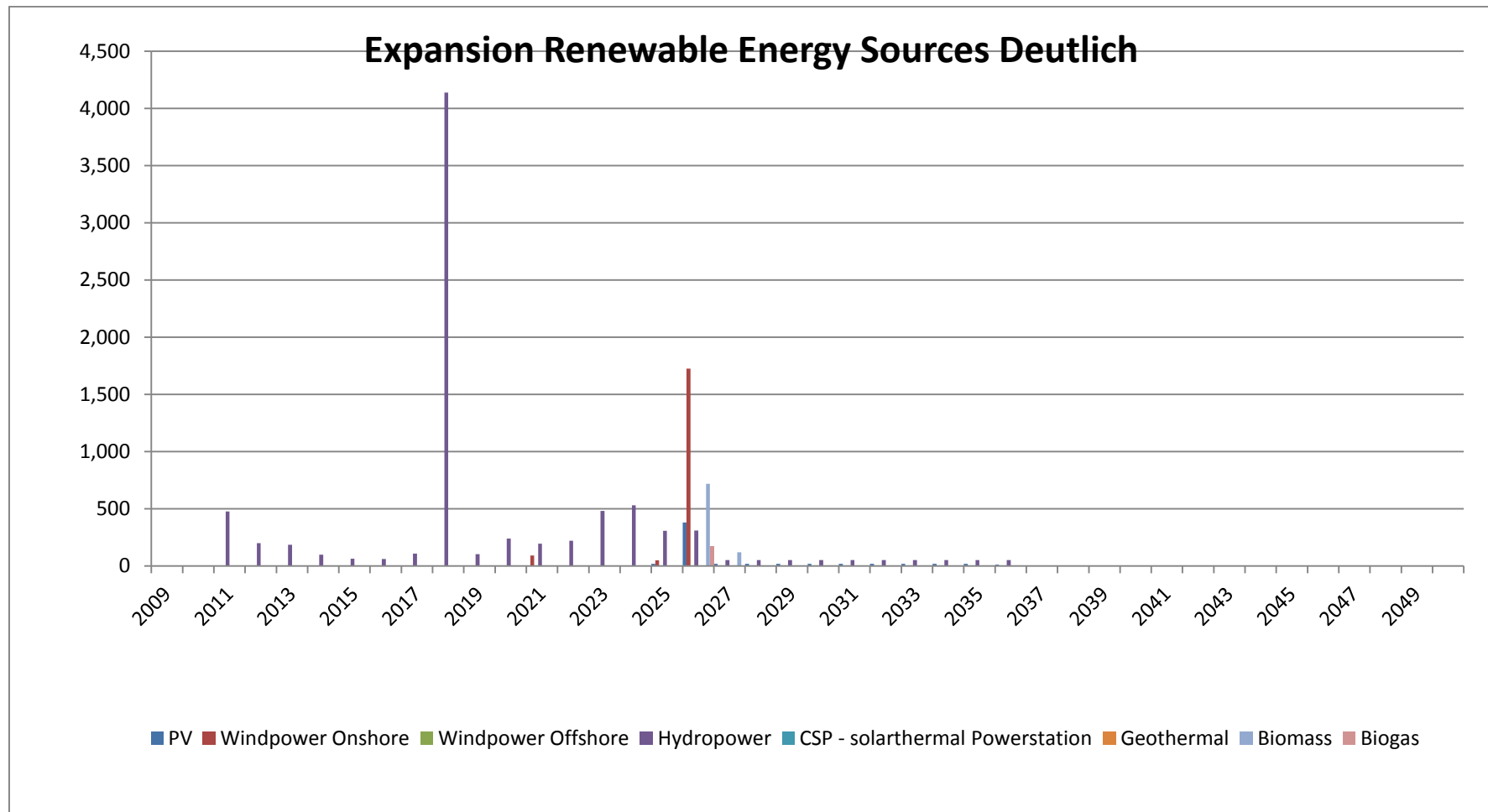
158

¹⁵⁸ The expansion in the time range 2036-2050 is zero for all renewable sources and therefore not shown in this graph









Results – Capacity and Expansion of all Scenarios

Expansion Mäßig

Expansion Mäßig	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	477.42	200	187	100	65	61	108	4140	103.39	239.67	195.97	220.85
CSP - solarthermal Powerstation	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	2657.3	0	0	0	0	0	0
Natural Gas	0	0	17.798	80.012	123.98	0	0	0	0	22.882	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	320.19	0	0	0	0	0	0
Nuclear Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expansion Mäßig	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	380	40	20	20	20	20	20	20	20	20	20
Windpower Onshore	0	0	21.826	1249.3	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	482.02	531.77	308.6	311.26	52.367	52.367	52.367	52.367	52.367	52.367	52.367	52.367	52.367	0
CSP - solarthermal Powerstation	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	108.85	1613.4	0	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear Power	0	0	0	0	0	0	0	0	0	706	0	0	0	0
Expansion Mäßig	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	20	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP - solarthermal Powerstation	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear Power	0	0	0	0	706	0	0	0	0	0	0	0	0	0

Capacity Mäßig

Capacity Maßig	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	7.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	6422.6	6422.6	6422.6	6422.6	6900	7100	7287	7387	7452	7513	7621	7729	7781.4	7833.7

CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	1585	1585	1585	1585	1585	1585	235	235	235	235	235	235	235	235
Lignite	8923.5	8923.5	8923.5	8923.5	8923.5	8923.5	4802.5	4802.5	3812.5	3800.5	3580.5	6141.3	4951.3	3357.3
Natural Gas	400	400	400	400	300	150	167.8	247.81	371.78	371.78	371.78	371.78	221.78	244.67
Crude Oil	1466	1466	1466	1466	1466	1466	315	315	315	315	0	320.19	320.19	320.19
Nuclear Power	706	706	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412
Capacity Maßig	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	0	380	420	440	460	480	500	520	540	560	580
Windpower Onshore	9.255	9.255	9.255	9.255	31.081	1280.4	1280.4	1280.4	1275.8	1273.2	1271.2	1271.2	1271.2	1271.2
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	7886.1	7938.5	7990.8	8043.2	8095.6	8147.9	8200.3	8252.7	8305	8357.4	8409.8	8462.1	8514.5	8566.9
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	235	235	235	235	235	235	235	235	235	0	0	0	0	0
Lignite	3207.3	3207.3	3007.3	2707.3	2707.3	2707.3	2707.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3
Natural Gas	244.67	244.67	244.67	244.67	244.67	244.67	353.51	1967	1967	1967	1967	1967	1967	1949.2
Crude Oil	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19
Nuclear Power	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412
Capacity Maßig	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	600	620	620	620	620	620	620	620	620	620	620	620	620	620
Windpower Onshore	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1271.2	1249.3

Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	8619.2	8619.2	8619.2	8619.2	8619.2	8619.2	8588.2	8588.2	8203.2	8203.2	8203.2	8203.2	8203.2	8203.2
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3	2657.3
Natural Gas	1869.1	1745.2	1745.2	1745.2	1745.2	1745.2	1722.3	1722.3	1722.3	1722.3	1722.3	1722.3	1722.3	1613.4
Crude Oil	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19	320.19
Nuclear Power	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412

Expansion Niedrig

Expansion Niedrig	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	477.42	200	187	100	65	61	108	4140	103.39	239.67	195.97	220.85
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	2959.7	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Crude Oil	0	0	0	0	0	0	45.89	216.59	0	0	0	0	0	0
Nuclear Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expansion Niedrig	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	380	40	20	20	20	20	20	20	20	0	0
Windpower Onshore	0	0	21.826	772.56	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	482.02	531.77	308.6	311.26	52.367	52.367	52.367	52.367	52.367	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	8.528	215.44	1793.9	0	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear Power	0	0	0	0	0	0	0	0	0	706	0	0	0	0
Expansion Niedrig	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear Power	0	0	0	0	305.12	0	0	0	0	0	0	0	0	0

Capacity Niedrig

Capacity Niedrig	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	7255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	6422.6	6422.6	6422.6	6422.6	6900	7100	7287	7387	7452	7513	7621	7729	7781.4	7833.7
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	1585	1585	1585	1585	1585	1585	235	235	235	235	235	235	235	235
Lignite	8923.5	8923.5	8923.5	8923.5	8923.5	8923.5	4802.5	4802.5	3812.5	3800.5	3580.5	6443.7	5253.7	3659.7
Natural Gas	400	400	400	400	300	150	150	150	150	150	150	150	0	0
Crude Oil	1466	1466	1466	1466	1466	1466	315	315	315	315	45.89	262.48	262.48	262.48
Nuclear Power	706	706	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412
Capacity Niedrig	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	0	380	420	440	460	480	500	520	540	560	560
Windpower Onshore	9.255	9.255	9.255	9.255	31.081	803.64	803.64	803.64	799.04	796.39	794.39	794.39	794.39	794.39
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	7886.1	7938.5	7990.8	8043.2	8095.6	8147.9	8200.3	8252.7	8305	8357.4	8409.8	8409.8	8409.8	8409.8
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	235	235	235	235	235	235	235	235	235	0	0	0	0	0
Lignite	3509.7	3509.7	3309.7	3009.7	3009.7	3009.7	3009.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7
Natural Gas	0	0	0	0	0	8.528	223.96	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9
Crude Oil	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48
Nuclear Power	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412
Capacity Niedrig	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	560	560	560	560	560	560	560	560	560	560	560	560	560	560
Windpower Onshore	794.39	794.39	794.39	794.39	794.39	794.39	794.39	794.39	794.39	794.39	794.39	794.39	794.39	772.56
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	8409.8	8409.8	8409.8	8409.8	8409.8	8409.8	8378.8	8378.8	7993.8	7993.8	7993.8	7993.8	7993.8	7993.8
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7	2959.7
Natural Gas	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2017.9	2009.3	1793.9
Crude Oil	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	262.48	216.59
Nuclear Power	1412	1412	1412	1412	1412	1412	1412	1412	1412	1011.1	1011.1	1011.1	1011.1	1011.1

Expansion Deutlich

Expansion Deutlich	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	6.0341	93.134	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	477.42	200	187	100	65	61	108	4140	103.39	239.67	195.97	220.85
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	1785.4	0	0	0	0	0	0
Natural Gas	0	0	468.52	17.656	117.14	75.29	0	0	32.663	182.93	4.997	0	10.503	83.618
Crude Oil	0	0	0	0	0	0	0	423.58	0	0	0	0	0	0
Nuclear Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expansion Deutlich	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	20	380	20	20	20	20	20	20	20	20	20	13.534
Windpower Onshore	0	0	49.109	1726.1	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	482.02	531.77	308.6	311.26	52.367	52.367	52.367	52.367	52.367	52.367	52.367	52.367	52.367	52.367
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	720	120	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	174.74	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Natural Gas	16.66	0	0	1428.1	0	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear Power	0	0	0	0	0	0	0	0	0	706	0	0	0	0
Expansion Deutlich	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crude Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear Power	0	0	0	0	706	0	0	0	0	0	0	0	0	0

Capacity Deutlich

Capacity Deutlich	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	7.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	9.255	15.289
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	6422.6	6422.6	6422.6	6422.6	6900	7100	7287	7387	7452	7513	7621	7729	7781.4	7833.7
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hard Coal	1585	1585	1585	1585	1585	1585	235	235	235	235	235	235	235	235
Lignite	8923.5	8923.5	8923.5	8923.5	8923.5	8923.5	4802.5	4802.5	3812.5	3800.5	3580.5	5269.4	4079.4	2485.4
Natural Gas	400	400	400	400	300	150	618.52	636.18	753.32	828.61	828.61	828.61	711.27	894.2
Crude Oil	1466	1466	1466	1466	1466	1466	315	315	315	315	0	423.58	423.58	423.58
Nuclear Power	706	706	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412
Capacity Deutlich	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	20	400	420	440	460	480	500	520	540	560	580
Windpower Onshore	108.42	108.42	108.42	108.42	157.53	1883.7	1883.7	1883.7	1879.1	1876.4	1874.4	1874.4	1874.4	1874.4
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	7886.1	7938.5	7990.8	8043.2	8095.6	8147.9	8200.3	8252.7	8305	8357.4	8409.8	8462.1	8514.5	8566.9
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	720	840	840	840	840	840
Biogas	0	0	0	0	0	0	0	0	174.74	174.74	174.74	174.74	174.74	174.74
Hard Coal	235	235	235	235	235	235	235	235	235	0	0	0	0	0
Lignite	2335.4	2335.4	2135.4	1835.4	1835.4	1835.4	1835.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4
Natural Gas	899.2	899.2	909.7	993.32	1010	1010	1010	2438.1	2438.1	2438.1	2438.1	2438.1	2438.1	1969.5
Crude Oil	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58
Nuclear Power	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412
Capacity Deutlich	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	593.53	593.53	593.53	593.53	593.53	593.53	593.53	593.53	593.53	593.53	593.53	593.53	593.53	573.53
Windpower Onshore	1874.4	1874.4	1874.4	1874.4	1874.4	1874.4	1874.4	1874.4	1868.4	1775.3	1775.3	1775.3	1775.3	1726.1

Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	8619.2	8671.6	8671.6	8671.6	8671.6	8671.6	8640.6	8640.6	8255.6	8255.6	8255.6	8255.6	8255.6	8255.6
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	840	840	840	840	840	840	840	840	840	840	840	840	840	840
Biogas	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74	174.74
Hard Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lignite	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4	1785.4
Natural Gas	1951.9	1834.7	1759.5	1759.5	1759.5	1726.8	1543.9	1538.9	1538.9	1528.4	1444.7	1428.1	1428.1	1428.1
Crude Oil	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58	423.58
Nuclear Power	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412	1412

Power Plant Related Data – Linear Expansion of given data

Technology Fixed Cost/Year

TechnologyFixedCost/Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	315100 0	272900 0	256380 0	239860 0	223340 0	206820 0	190300 0	176300 0	162300 0	148300 0	134300 0	120300 0	118210 0	116120 0
Windpower Onshore	132000 0	132000 0	129200 0	126400 0	123600 0	120800 0	118000 0	115000 0	112000 0	109000 0	106000 0	103000 0	102500 0	102000 0
Windpower Offshore	350000 0	330000 0	316500 0	303000 0	289500 0	276000 0	262500 0	252000 0	241500 0	231000 0	220500 0	210000 0	207000 0	204000 0
Hydropower	273000 0	273000 0	275160 0	277320 0	279480 0	281640 0	283800 0	286260 0	288720 0	291180 0	293640 0	296100 0	298310 0	300520 0
CSP	462800 0	462800 0	450880 0	438960 0	427040 0	415120 0	403200 0	391260 0	379320 0	367380 0	355440 0	343500 0	337280 0	331060 0
Geothermal	125000 00	123500 00	120640 00	117780 00	114920 00	112060 00	109200 00	108276 00	107352 00	106428 00	105504 00	104580 00	103432 00	102284 00
Biomass	340500 0	340800 0	340180 0	339560 0	338940 0	338320 0	337700 0	336700 0	335700 0	334700 0	333700 0	332700 0	332760 0	332820 0

Biogas	361600 0	358400 0	354800 0	351200 0	347600 0	344000 0	340400 0	336540 0	332680 0	328820 0	324960 0	321100 0	319790 0	318480 0
Hard Coal	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0	130000 0
Brown Coal	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0
Natural Gas	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000
Crude Oil	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0	110000 0
Nuclear Power	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0	135000 0
TechnologyFixedCost/Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	114030 0	111940 0	109850 0	107760 0	105670 0	103580 0	101490 0	994000	988300	982600	976900	971200	965500	959800
Windpower Onshore	101500 0	101000 0	100500 0	100000 0	995000	990000	985000	980000	976000	972000	968000	964000	960000	956000
Windpower Offshore	201000 0	198000 0	195000 0	192000 0	189000 0	186000 0	183000 0	180000 0	177000 0	174000 0	1710000	1680000	1650000	1620000
Hydropower	302730 0	304940 0	307150 0	309360 0	311570 0	313780 0	315990 0	318200 0	319610 0	321020 0	3224300	3238400	3252500	3266600
CSP	324840 0	318620 0	312400 0	306180 0	299960 0	293740 0	287520 0	281300 0	279160 0	277020 0	2748800	2727400	2706000	2684600
Geothermal	10113600	9998800	9884000	9769200	9654400	9539600	9424800	9310000	9216500	9123000	9029500	8936000	8842500	8749000
Biomass	3328800	3329400	3330000	3330600	3331200	3331800	3332400	3333000	3327800	3322600	3317400	3312200	3307000	3301800
Biogas	3171700	3158600	3145500	3132400	3119300	3106200	3093100	3080000	3067000	3054000	3041000	3028000	3015000	3002000
Hard Coal	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000
Brown Coal	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000
Natural Gas	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000	700000
Crude Oil	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000
Nuclear Power	135000	135000	135000	135000	135000	135000	135000	135000	135000	135000	1350000	1350000	1350000	1350000

	0	0	0	0	0	0	0	0	0	0		000	0	0
TechnologyFixedCost/Year	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	954100	948400	942700	937000	933600	930200	926800	923400	920000	916600	913200	909800	906400	903000
Windpower Onshore	952000	948000	944000	940000	936000	932000	928000	924000	920000	916000	912000	908000	904000	900000
Windpower Offshore	1590000	1560000	1530000	1500000	1480000	1460000	1440000	1420000	1400000	1380000	1360000	1340000	1320000	1300000
Hydropower	3280700	3294800	3308900	3323000	3340400	3357800	3375200	3392600	3410000	3427400	3444800	3462200	3479600	3497000
CSP	2663200	2641800	2620400	2599000	2589600	2580200	2570800	2561400	2552000	2542600	2533200	2523800	2514400	2505000
Geothermal	8655500	8562000	8468500	8375000	8265000	8155000	8045000	7935000	7825000	7715000	7605000	7495000	7385000	7275000
Biomass	3296600	3291400	3286200	3281000	3272500	3264000	3255500	3247000	3238500	3230000	3221500	3213000	3204500	3196000
Biogas	2989000	2976000	2963000	2950000	2940800	2931600	2922400	2913200	2904000	2894800	2885600	2876400	2867200	2858000
Hard Coal	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000	1300000
Brown Coal	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000
Natural Gas	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000	7000000
Crude Oil	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000	1100000
Nuclear Power	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000	1350000

Technology Variable Costs Mäßig

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	20.16	20.88	21.096	21.312	21.528	21.744	21.96	22.176	22.392	22.608	22.824	23.04	23.148	23.256
Biogas	21.6	21.6	22.032	22.464	22.896	23.328	23.76	24.12	24.48	24.84	25.2	25.56	25.632	25.704
Hard Coal	17.39 52	17.75 52	18.4464	19.1376	19.8288	20.52	21.2112	21.9024	22.5936	23.2848	23.976	24.6672	25.1208	25.5744
Brown Coal	14.30 68	14.53 50927	15.1641 854	15.7932 78	16.4223 707	17.0514 634	17.6805 561	18.3096 488	18.9387 415	19.5678 341	20.1969 268	20.8260 195	21.2547 122	21.6834 049
Natural Gas	24.77 88	27.65 88	28.6536	29.6484	30.6432	31.638	32.6328	33.4836	34.3344	35.1852	36.036	36.8868	37.7082	38.5296
Crude Oil	32.25 96	35.85 96	36.9912	38.1228	39.2544	40.386	41.5176	42.5772	43.6368	44.6964	45.756	46.8156	47.8854	48.9552
Nuclear Power	4.80	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.96	5.02
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	23.36 4	23.47 2	23.58	23.688	23.796	23.904	24.012	24.12	24.3	24.48	24.66	24.84	25.02	25.2

Biogas	25.77 6	25.84 8	25.92	25.992	26.064	26.136	26.208	26.28	26.316	26.352	26.388	26.424	26.46	26.496
Hard Coal	26.02 8	26.48 16	26.9352	27.3168	27.6984	28.08	28.4616	28.8432	29.1859 2	29.5286 4	29.8713 6	30.2140 8	30.5568	30.8995 2
Brown Coal	22.11 20976	22.54 07902	22.9694 829	23.3981 756	23.8268 683	24.2555 61	24.6842 537	25.1129 463	25.5817 19	26.0504 917	26.5192 644	26.9880 371	27.4568 098	27.9255 824
Natural Gas	39.35 1	40.17 24	40.9938	41.6712	42.3486	43.026	43.7034	44.3808	44.9704 8	45.5601 6	46.1498 4	46.7395 2	47.3292	47.9188 8
Crude Oil	50.02 5	51.09 48	52.1646	53.0184	53.8722	54.726	55.5798	56.4336	57.1701 6	57.9067 2	58.6432 8	59.3798 4	60.1164	60.8529 6
Nuclear Power	5.08	5.14	5.20	5.30	5.40	5.50	5.60	5.70	5.84	5.98	6.12	6.26	6.40	6.54
	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	25.38	25.56	25.74	25.92	26.136	26.352	26.568	26.784	27	27.216	27.432	27.648	27.864	28.08
Biogas	26.53 2	26.56 8	26.604	26.64	26.676	26.712	26.748	26.784	26.82	26.856	26.892	26.928	26.964	27
Hard Coal	31.24 224	31.58 496	31.9276 8	32.2704	32.58	32.8896	33.1992	33.5088	33.8184	34.128	34.4376	34.7472	35.0568	35.3664
Brown Coal	28.39 43551	28.86 31278	29.3319 005	29.8006 732	30.2293 659	30.6580 585	31.0867 512	31.5154 439	31.9441 366	32.3728 293	32.8015 22	33.2302 146	33.6589 073	34.0876
Natural Gas	48.50 856	49.09 824	49.6879 2	50.2776	50.667	51.0564	51.4458	51.8352	52.2246	52.614	53.0034	53.3928	53.7822	54.1716
Crude Oil	61.58 952	62.32 608	63.0626 4	63.7992	64.329	64.8588	65.3886	65.9184	66.4482	66.978	67.5078	68.0376	68.5674	69.0972
Nuclear Power	6.68	6.82	6.96	7.10	7.30	7.50	7.70	7.90	8.10	8.30	8.50	8.70	8.90	9.10

Technology Variable Costs Niedrig

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	20.16	20.88	21.10	21.31	21.53	21.74	21.96	22.18	22.39	22.61	22.82	23.04	23.15	23.26
Biogas	21.60	21.60	22.03	22.46	22.90	23.33	23.76	24.12	24.48	24.84	25.20	25.56	25.63	25.70
Hard Coal	15.739 2	16.09 92	16.33 68	16.574 4	16.812	17.0496	17.2872	17.5968	17.9064	18.216	18.5256	18.8352	19.0785 6	19.3219 2
Brown Coal	12.302 8	12.41 6946 3	12.73 1492 7	13.046 039	13.3605 854	13.6751 317	13.9896 78	14.3042 244	14.6187 707	14.9333 171	15.2478 634	15.5624 098	15.7967 961	16.0311 824
Natural Gas	23.764 8	24.84 48	25.16 22	25.479 6	25.797	26.1144	26.4318	26.6772	26.9226	27.168	27.4134	27.6588	28.0076 4	28.3564 8
Crude Oil	30.921 6	31.28 16	31.63 14	31.981 2	32.331	32.6808	33.0306	33.4524	33.8742	34.296	34.7178	35.1396	35.5798 8	36.0201 6
Nuclear Power	4.8	4.632 5	4.632 5	4.6325	4.6325	4.6325	4.6325	4.6325	4.6325	4.6325	4.6325	4.6325	4.6925	4.7525
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Biomass	23.36	23.47	23.58	23.69	23.80	23.90	24.01	24.12	24.30	24.48	24.66	24.84	25.02	25.20
Biogas	25.78	25.85	25.92	25.99	26.06	26.14	26.21	26.28	26.32	26.35	26.39	26.42	26.46	26.50
Hard Coal	19.565 28	19.80 864	20.05 2	20.295 36	20.5387 2	20.7820 8	21.0254 4	21.2688	21.4401 6	21.6115 2	21.7828 8	21.9542 4	22.1256	22.2969 6
Brown Coal	16.265 5688	16.49 9955 1	16.73 4341 5	16.968 7278	17.2031 141	17.4375 005	17.6718 868	17.9062 732	18.1406 595	18.3750 459	18.6094 322	18.8438 185	19.0782 049	19.3125 912
Natural Gas	28.705 32	29.05 416	29.40 3	29.751 84	30.1006 8	30.4495 2	30.7983 6	31.1472	31.4240 4	31.7008 8	31.9777 2	32.2545 6	32.5314	32.8082 4
Crude Oil	36.460 44	36.90 072	37.34 1	37.709 28	38.0775 6	38.4458 4	38.8141 2	39.1824	39.5506 8	39.9189 6	40.2872 4	40.6555 2	41.0238	41.3920 8
Nuclear Power	4.8125	4.872 5	4.932 5	5.0325	5.1325	5.2325	5.3325	5.4325	5.5725	5.7125	5.8525	5.9925	6.1325	6.2725
	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	25.38	25.56	25.74	25.92	26.14	26.35	26.57	26.78	27.00	27.22	27.43	27.65	27.86	28.08
Biogas	26.53	26.57	26.60	26.64	26.68	26.71	26.75	26.78	26.82	26.86	26.89	26.93	26.96	27.00
Hard Coal	22.468 32	22.63 968	22.81 104	22.982 4	23.1566 4	23.3308 8	23.5051 2	23.6793 6	23.8536	24.0278 4	24.2020 8	24.3763 2	24.5505 6	24.7248
Brown Coal	19.546 9776	19.78 1363 9	20.01 5750 2	20.250 1366	20.4444 429	20.6387 493	20.8330 556	21.0273 62	21.2216 683	21.4159 746	21.6102 81	21.8045 873	21.9988 937	22.1932
Natural Gas	33.085 08	33.36 192	33.63 876	33.915 6	34.1001 6	34.2847 2	34.4692 8	34.6538 4	34.8384	35.0229 6	35.2075 2	35.3920 8	35.5766 4	35.7612
Crude Oil	41.760 36	42.12 864	42.49 692	42.865 2	43.0987 2	43.3322 4	43.5657 6	43.7992 8	44.0328	44.2663 2	44.4998 4	44.7333 6	44.9668 8	45.2004
Nuclear Power	6.4125	6.552	6.692	6.8325	7.0325	7.2325	7.4325	7.6325	7.8325	8.0325	8.2325	8.4325	8.6325	8.8325

Technology Variable Costs Deutlich

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	20.16	20.88	21.10	21.31	21.53	21.74	21.96	22.18	22.39	22.61	22.82	23.04	23.15	23.26
Biogas	21.60	21.60	22.03	22.46	22.90	23.33	23.76	24.12	24.48	24.84	25.20	25.56	25.63	25.70
Hard Coal	18.72	19.44	20.66	21.87	23.09	24.31	25.52	26.74	27.96	29.17	30.39	31.61	32.58	33.55
Brown Coal	15.91	16.4631 707	17.6175 415	18.77 1912 2	19.9262 829	21.0806 537	22.2350 244	23.3893 951	24.5437 659	25.6981 366	26.8525 073	28.0068 78	29.0410 088	30.0751 395
Natural Gas	25.59	29.19	30.9342	32.67 84	34.4226	36.1668	37.911	39.6552	41.3994	43.1436	44.8878	46.632	47.9553 6	49.2787 2
Crude Oil	33.33	38.01	39.9954	41.98 08	43.9662	45.9516	47.937	49.9944	52.0518	54.1092	56.1666	58.224	59.6251 2	61.0262 4
Nuclear Power	4.80	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.10	5.16
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	23.36	23.47	23.58	23.69	23.80	23.90	24.01	24.12	24.30	24.48	24.66	24.84	25.02	25.20

Biogas	25.78	25.85	25.92	25.99	26.06	26.14	26.21	26.28	26.32	26.35	26.39	26.42	26.46	26.50
Hard Coal	34.53	35.50	36.48	37.30	38.13	38.96	39.79	40.62	41.46	42.29	43.13	43.96	44.80	45.63
Brown Coal	31.10 92702	32.1434 01	33.1775 317	34.21 1662 4	35.2457 932	36.2799 239	37.3140 546	38.3481 854	39.3021 561	40.2561 268	41.2100 976	42.1640 683	43.1180 39	44.0720 098
Natural Gas	50.60 208	51.9254 4	53.2488	54.64 416	56.0395 2	57.4348 8	58.8302 4	60.2256	61.4364	62.6472	63.858	65.0688	66.2796	67.4904
Crude Oil	62.42 736	63.8284 8	65.2296	66.70 272	68.1758 4	69.6489 6	71.1220 8	72.5952	73.9068	75.2184	76.53	77.8416	79.1532	80.4648
Nuclear Power	5.22	5.28	5.34	4.43	3.52	2.61	1.70	0.79	1.43	2.08	2.72	3.37	4.01	4.66
	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Windpower Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydropower	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	25.38	25.56	25.74	25.92	26.14	26.35	26.57	26.78	27.00	27.22	27.43	27.65	27.86	28.08
Biogas	26.53	26.57	26.60	26.64	26.68	26.71	26.75	26.78	26.82	26.86	26.89	26.93	26.96	27.00
Hard Coal	46.47	47.30	48.14	48.97	49.81	50.64	51.47	52.30	53.14	53.97	54.80	55.63	56.47	57.30
Brown Coal	45.02 59805	45.9799 512	46.9339 22	47.88 7892 7	48.8819 434	49.8759 941	50.8700 449	51.8640 956	52.8581 463	53.8521 971	54.8462 478	55.8402 985	56.8343 493	57.8284
Natural Gas	68.70 12	69.912	71.1228	72.33 36	73.4926 8	74.6517 6	75.8108 4	76.9699 2	78.129	79.2880 8	80.4471 6	81.6062 4	82.7653 2	83.9244
Crude Oil	81.77 64	83.088	84.3996	85.71 12	86.9415 6	88.1719 2	89.4022 8	90.6326 4	91.863	93.0933 6	94.3237 2	95.5540 8	96.7844 4	98.0148
Nuclear Power	5.30	5.95	6.59	7.24	7.44	7.64	7.84	8.04	8.24	8.44	8.64	8.84	9.04	9.24

Efficiency/Year

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PV	0.81	0.81	0.811	0.812	0.813	0.814	0.815	0.8158	0.8166	0.8174	0.8182	0.819	0.8199	0.8208
Windpower Onshore	0.23401826	0.23401826	0.23515982	0.23630137	0.23744292	0.23858447	0.23972603	0.24200913	0.24429224	0.24657534	0.24885845	0.25114155	0.25285388	0.25456621
Windpower Offshore	0.3652968	0.3652968	0.37214612	0.37899543	0.38584475	0.39269406	0.39954338	0.40410959	0.4086758	0.41324201	0.41780822	0.42237443	0.42351598	0.42465753
Hydropower	0.62728311	0.62728311	0.62726027	0.62723744	0.62721461	0.62719178	0.62716895	0.62767123	0.62817352	0.6286758	0.62917808	0.62968037	0.62996575	0.63025114
CSP	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913	0.74200913
Geothermal	0.69634703	0.69634703	0.69634703	0.69634703	0.69634703	0.69634703	0.69634703	0.70388128	0.71141553	0.71894977	0.72648402	0.73401826	0.73590183	0.73778539
Biomass	0.80251142	0.80136986	0.80045662	0.79954338	0.79863014	0.79771689	0.79680365	0.79611872	0.79543379	0.79474886	0.79406393	0.793379	0.79200913	0.79063927
Biogas	0.375	0.375	0.3762	0.3774	0.3786	0.3798	0.381	0.3834	0.3858	0.3882	0.3906	0.393	0.3937	0.3944
Hard Coal	0.458	0.458	0.4608	0.4636	0.4664	0.4692	0.472	0.4776	0.4832	0.4888	0.4944	0.5	0.50146	0.50246
Brown Coal	0.43	0.43	0.4318	0.4336	0.4354	0.4372	0.439	0.4448	0.4506	0.4564	0.4622	0.468	0.4703	0.4726
Natural Gas	0.581	0.581	0.583	0.585	0.587	0.589	0.591	0.593	0.595	0.597	0.599	0.601	0.603	0.605
Crude Oil	0.43	0.43	0.4318	0.4336	0.4354	0.4372	0.439	0.4448	0.4506	0.4564	0.4622	0.468	0.4703	0.4726
Nuclear Power	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036

PV	0.821 7	0.8226	0.823 5	0.8244	0.8253	0.8262	0.8271	0.828	0.8289	0.8298	0.8307	0.8316	0.8325	0.8334
Windpower Onshore	0.256 2785 4	0.25799 087	0.259 7032	0.2614 1553	0.2631 2785	0.2648 4018	0.2665 5251	0.2682 6484	0.2694 0639	0.2705 4795	0.2716 895	0.2728 3105	0.2739 726	0.2751 1416
Windpower Offshore	0.425 7990 9	0.42694 064	0.428 0821 9	0.4292 2374	0.4303 653	0.4315 0685	0.4326 484	0.4337 8995	0.4343 6073	0.4349 3151	0.4355 0228	0.4360 7306	0.4366 4384	0.4372 1461
Hydropower	0.630 5365 3	0.63082 192	0.631 1073 1	0.6313 9269	0.6316 7808	0.6319 6347	0.6322 4886	0.6325 3425	0.6328 1963	0.6331 0502	0.6333 9041	0.6336 758	0.6339 6119	0.6342 4658
CSP	0.742 0091 3	0.74200 913	0.742 0091 3	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913
Geothermal	0.739 6689 5	0.74155 251	0.743 4360 7	0.7453 1963	0.7472 032	0.7490 8676	0.7509 7032	0.7528 5388	0.7531 3927	0.7534 2466	0.7537 1005	0.7539 9543	0.7542 8082	0.7545 6621
Biomass	0.789 2694 1	0.78789 954	0.786 5296 8	0.7851 5982	0.7837 8995	0.7824 2009	0.7810 5023	0.7796 8037	0.7789 3836	0.7781 9635	0.7774 5434	0.7767 1233	0.7759 7032	0.7752 2831
Biogas	0.395 1	0.3958	0.396 5	0.3972	0.3979	0.3986	0.3993	0.4	0.4003	0.4006	0.4009	0.4012	0.4015	0.4018
Hard Coal	0.503 4025	0.50433 679	0.505 2697	0.5062 0235	0.5071 3492	0.5080 6747	0.5090 0001	0.509	0.509	0.509	0.509	0.509	0.509	0.509
Brown Coal	0.474 9	0.4772	0.479 5	0.4818	0.4841	0.4864	0.4887	0.491	0.491	0.491	0.491	0.491	0.491	0.491
Natural Gas	0.607	0.609	0.611	0.613	0.615	0.617	0.619	0.621	0.621	0.621	0.621	0.621	0.621	0.621
Crude Oil	0.474 9	0.4772	0.479 5	0.4818	0.4841	0.4864	0.4887	0.491	0.491	0.491	0.491	0.491	0.491	0.491
Nuclear Power	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
PV	0.834 3	0.8352	0.836 1	0.837	0.838	0.839	0.84	0.841	0.842	0.843	0.844	0.845	0.846	0.847

Windpower Onshore	0.276 2557 1	0.27739 726	0.278 5388 1	0.2796 8037	0.2808 2192	0.2819 6347	0.2831 0502	0.2842 4658	0.2853 8813	0.2865 2968	0.2876 7123	0.2888 1279	0.2899 5434	0.2910 9589
Windpower Offshore	0.437 7853 9	0.43835 616	0.438 9269 4	0.4394 9772	0.4400 6849	0.4406 3927	0.4412 1005	0.4417 8082	0.4423 516	0.4429 2237	0.4434 9315	0.4440 6393	0.4446 347	0.4452 0548
Hydropower	0.634 5319 6	0.63481 735	0.635 1027 4	0.6353 8813	0.6356 9635	0.6360 0457	0.6363 1279	0.6366 21	0.6369 2922	0.6372 3744	0.6375 4566	0.6378 5388	0.6381 621	0.6384 7032
CSP	0.742 0091 3	0.74200 913	0.742 0091 3	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913	0.7420 0913
Geothermal	0.754 8516	0.75513 699	0.755 4223 7	0.7557 0776	0.7559 9315	0.7562 7854	0.7565 6393	0.7568 4932	0.7571 347	0.7574 2009	0.7577 0548	0.7579 9087	0.7582 7626	0.7585 6164
Biomass	0.774 4863	0.77374 429	0.773 0022 8	0.7722 6027	0.7718 0365	0.7713 4703	0.7708 9041	0.7704 3379	0.7699 7717	0.7695 2055	0.7690 6393	0.7686 0731	0.7681 5068	0.7676 9406
Biogas	0.402 1	0.4024	0.402 7	0.403	0.4032	0.4034	0.4036	0.4038	0.404	0.4042	0.4044	0.4046	0.4048	0.405
Hard Coal	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509
Brown Coal	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491
Natural Gas	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621	0.621
Crude Oil	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491	0.491
Nuclear Power	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

10.1 Abstract englisch

The main contribution of this master thesis is a proposal for the future electricity capacity of Romania, divided by power generation forms. To estimate the future electricity mix, a linear programming model was calculated. Several input factors, such as the specific power plant efficiency and utilization for renewable sources, fuel prices and CO₂ certificate prices, power plant life times, construction times, technical constraints as well as the electricity demand for the planning horizon were needed to calculate the hourly electricity production, the yearly capacity and the yearly extension by power plant within the years from 2009 to 2050. The determination of the future electricity mix of Romania is depended on the fuel prices and the CO₂ certificate prices over the planning horizon. To show the impact of changing price forecasts on the future electricity mix of Romania, three different fuel and CO₂ price scenarios were used.

The calculation of the three different electricity mix scenarios shows the enormous impact of changing fuel and CO₂ certificate prices on the expansion of renewable/thermal power and on the installed capacity respectively. The higher the fuel/ CO₂ price forecast, the bigger the investment in renewable sources, while lower fuel and CO₂ certificate prices reduce the commitment for investment in renewable sources – which finally results in the higher extension of thermal power plants.

10.2 Abstract deutsch

Der Hauptbeitrag dieser Masterthese ist die Berechnung der Elektrizitätskapazität eines bevorstehenden rumänischen Kraftwerkparks. Um den zukünftigen Elektrizitätsmix vorherzusagen, wurde ein Modell eines linearen Programms entwickelt das anhand unterschiedlicher Faktoren, die jährliche Kapazität, die Expansion und die stündlich geforderte Stromproduktion im Zeitraum 2009 – 2050 berechnet. Faktoren wie z.B. die Kraftwerksauslastung und -effizienz bei erneuerbaren Energien, die Leistungsfähigkeit fossiler Brennstoffe für kalorische Kraftwerke und die Brennstoffpreise und Preise für CO₂ - Zertifikate sowie der zukünftige Stromverbrauch Rumäniens bilden dabei die Grundlage des linearen

Programms. Die Ermittlung des zukünftigen Elektrizitätsmix Rumäniens ist demnach abhängig von den Brennpreisen und von den CO₂ –Zertifikatspreisen. Um die Effekte der sich ändernden Preisprognosen auf den künftigen Elektrizitätsmix von Rumänien aufzuzeigen, wurden drei Preisszenarien (für Brennstoff und CO₂ Zertifikate) untersucht. Die Berechnung der drei verschiedenen Elektrizitätsmixszenarien zeigt die enorme Auswirkung der variierenden Brennstoff- und CO₂ -Zertifikatspreise auf die Expansion und der neuen Kapazitäten der erneuerbaren bzw. thermischen Kraftwerkserweiterungen.

10.3 Lebenslauf

Nachname / Vorname	Wüster Bernhard
Geburtsdatum	18.02.1987
Geburtsort	St. Pölten
Staatsangehörigkeit	Österreich
Ausbildung	
Universität Wien	Oktober 2009 – Oktober 2011
Diplomarbeit	Electricity Mix Forecast for Romania
Fachhochschule Krems	September 2006 – September 2009
Bachelorarbeit	Die Bedeutung der Kapitalmarktkommunikation für institutionelle Investoren
Stiftsgymnasium Melk	1997 – 2005

Berufserfahrung	2007 – 2011
Praktikant Controlling	VERBUND AG
Praktikant Projekt- und Prozessmanagement	ANDRITZ AG
Sprachkenntnisse	
Deutsch	Muttersprache
Englisch	Kompetente Sprachverwendung
Spanisch	Kompetente Sprachverwendung